Volume 29 JULY, 1945 Number 7

BULLETIN
of the
American Association *of* Petroleum Geologists

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of the

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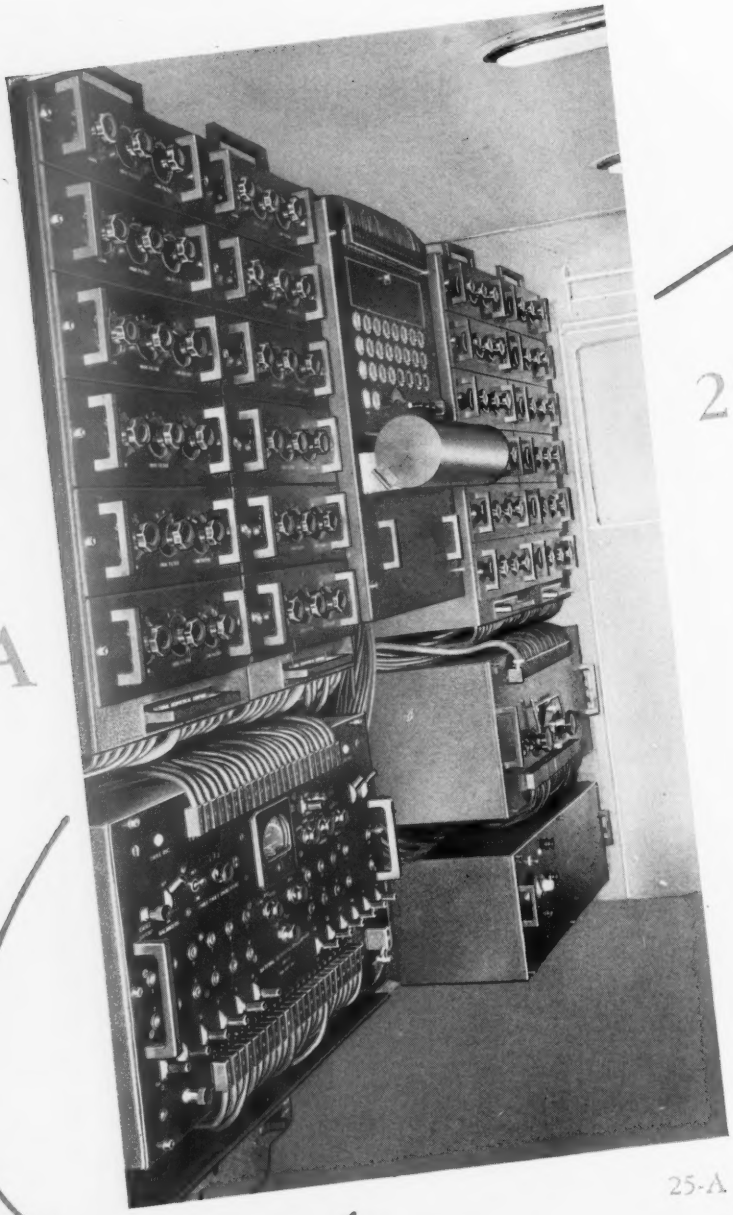

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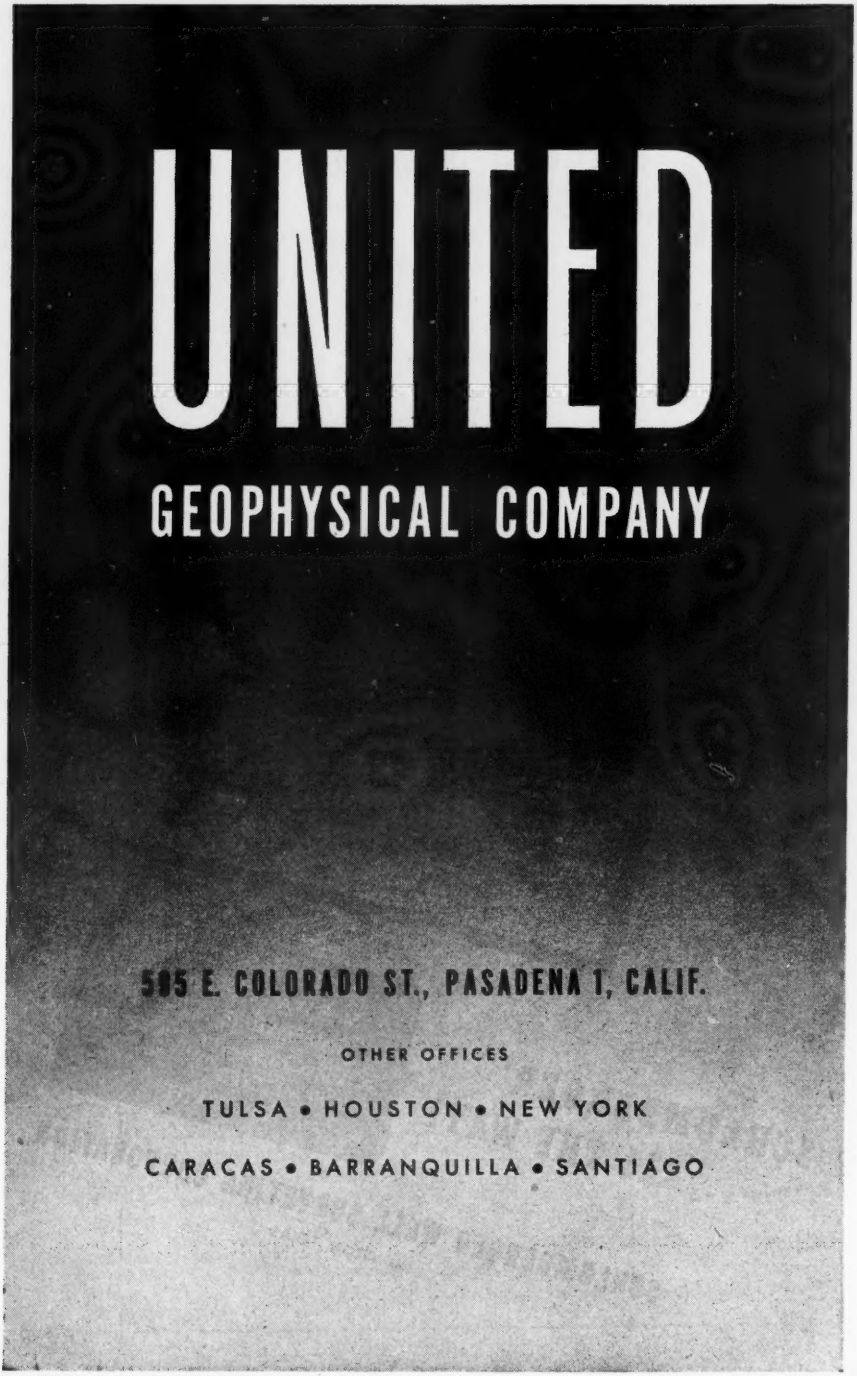
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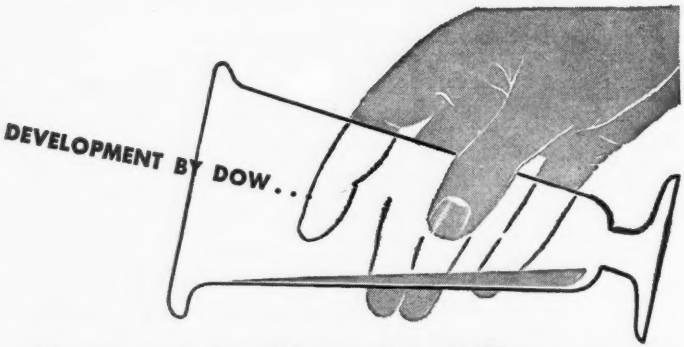

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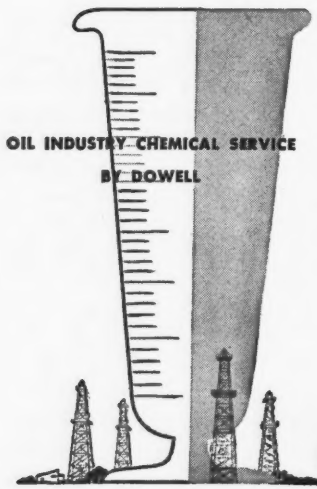

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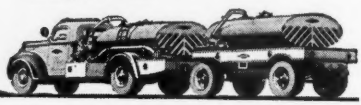

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Volume 29 Number 7

BULLETIN
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JULY, 1945

RESOURCES AND RESOURCEFULNESS[1]

IRA H. CRAM[2]
Chicago, Illinois

INTRODUCTION

Standing at the very head of a long list of difficulties which consistently confront the oil industry is the problem of discovering adequate quantities of crude oil and gas. To date the industry, by developing an unexcelled resourcefulness, has been eminently successful in solving this major problem. The members of this Association—geologists, geophysicists, geochemists, teachers, petroleum engineers, scouts, production men, executives, operators, and others—have made a signal contribution to the industry's success. Since the organization of the Association 28 years ago, almost 26 billion barrels of crude oil have been won from the earth, and a little over 49 trillion cubic feet of natural gas have been produced and marketed in the United States. In addition, the estimated proved reserve of crude oil has been enlarged by approximately 14 billion barrels, and the estimated proved reserve of natural gas has been increased between 90 and 100 trillion cubic feet.

The accomplishment of finding 40 billion barrels of crude oil and between 140 and 150 trillion cubic feet of gas in 28 years is a record of which the industry can be justly proud. But that accomplishment is now history; what of the future? Two questions immediately present themselves. How large are our resources of oil and gas? Whatever they may be, are we going to continue to be resourceful enough to develop them economically? Nobody knows or has any way of knowing even the approximately correct answers to these questions. Partial answers to both questions ventured by students are numerous and varied. I do not propose to offer even partial answers, but merely to analyze certain aspects of the questions in a way that may prove to be helpful.

[1] Presidential address, thirtieth annual meeting of the Association, Tulsa, March 27, 1945. Published by permission of the chief geologist of The Pure Oil Company.

[2] Assistant to the chief geologist of The Pure Oil Company. The writer expresses his appreciation to A. Rodger Denison, A. I. Levorsen, Carl C. Addison, Theron Wasson, C. Plummer, W. E. Wrather, and Carey Croneis, all of whom read the manuscript and offered helpful suggestions.

RESOURCES

The nation's resources of oil and gas consist of the undiscovered reserve and the discovered reserve. The latter is subdivided into the proved reserve and the reserve already discovered but not recoverable at present prices and with present production methods.

DISCOVERED RESERVE

The total area in the United States covered by oil and gas fields is approximately 26,000 square miles. Approximately one-third of this area is productive of oil. From these fields approximately $29\frac{3}{4}$ billion barrels of crude oil and almost 61 trillion cubic feet of gas have been produced, and the proved reserve is estimated at 20 billion barrels of oil and 114 trillion cubic feet of gas. The reserve of crude oil not recoverable at present prices and with present production methods may well be 25 or more billion barrels. We have discovered not only the commonly estimated 50 billion barrels of oil; we may well have discovered over 50 per cent more. This presently unrecoverable reserve is a resource of great importance, insufficiently stressed by many observers. How to *recover* an ever-increasing percentage of the oil we *discover* presents a challenge to the industry's resourcefulness in general, and to the resourcefulness of geologists and engineers in particular.

UNDISCOVERED RESERVE

The undiscovered reserve of oil and gas lies beneath certain oil and gas fields that have not been thoroughly tested to basement and beneath an area of approximately 1,600,000 square miles outside the producing fields. Scarcely a sizeable part of this prospective territory has escaped attention; yet enormous areas have hardly been scratched by the drill. These largely undrilled areas make up the horizontal frontier. The vertical frontier lies below the formations normally tested and below the depths customarily reached in drilling.

Faith in the existence of a large number of oil and gas pools in these frontiers as well as in the more densely drilled areas is justified by the general geology and history of discovery. In the horizontal frontier of thick, warped, changing sediments, traps capable of holding oil and gas can not fail to exist. Some of these traps will be detected in advance of drilling by geological investigations; others will be found by geologists using the geologic data revealed by drilling. There are undiscovered traps and known traps that have not been drilled to sufficient depths in the more densely drilled areas between the horizontal frontier and the producing fields.

In considering the prospects of the more densely drilled areas, and of both the horizontal and vertical frontiers, the amount of condemning drilling is a most pertinent factor. Only structurally or stratigraphically well-located dry holes that have been drilled through all known producing formations or through the entire sedimentary column or to 15,000 feet can be considered as truly significant. Only those drilled through the sedimentary column may be judged as truly condemning.

Without attempting to present a complete discussion of deep drilling, certain significant facts should be pointed out. In a prospective area of approximately 150,000 square miles, most of which is in the Gulf Coast states, the sedimentary column is thicker than 15,000 feet, and in this large area only 5 wells have been drilled to 15,000 feet or deeper. In the area in which the sedimentary column is thinner than 15,000 feet, test wells to basement are rare indeed, except where the column is thinner than 5,000 feet. Only approximately 325 wells have reached basement between the depths of 5,000 and 15,000 feet in an area of approximately 850,000 square miles, and approximately half of these are located in a few California producing fields two of which produce from the basement. Even if all the dry holes reaching basement below 5,000 feet were well located structurally or stratigraphically, the amount of truly condemning testing is small. The number of test wells reaching basement above 5,000 feet in an area of approximately 600,000 square miles is inadequate.

How much of the oil and gas cached in the enormous horizontal and vertical prospective territories will eventually be found is anybody's guess. Until well-located dry holes have been drilled through the sedimentary column or to the limits of drilling equipment on a high percentage of the geologic anomalies that could be traps and on producing traps, there will be no nearly conclusive evidence that the end of discovery is in sight. However large the undiscovered reserve may be, it is of no practical importance unless it is turned into the proved reserve. The conversion of undiscovered reserve to proved reserve has never been easy, except in retrospect, and it can only become less easy. We who are charged with the duty of finding and developing oil and gas fields must first find and develop a resourcefulness adequate to the task.

RESOURCEFULNESS

Introduction.—The nation's resources of oil and gas are developed through the efforts of an army of men and industries cooperating in an atmosphere of free enterprise and private ownership. Various phases of the complicated procedure are dominated by men with special training and knowledge. The all-important initial phase—exploration—is naturally dominated by geologists who are specialists in the composition and structure of that part of the shell of the earth in which the deposits of oil and gas lie hidden. Resourceful geologists have applied their science to the solution of a great variety of problems of exploration and exploitation, so that today geology permeates the producing branch of the industry, and geologists occupy positions ranging in rank from trainee to company president or owner. Their horizon is virtually unlimited, and the successful capture of our hidden reserves of oil and gas depends in large part upon their performance. The resourcefulness of geologists is, therefore, an important component of the industry's resourcefulness, and, as such, it is worthy of special consideration.

GEOLOGIC TOOLS

During the past 25 years the precision of geologic investigations has been increased by the use of new geologic tools—plane table and alidade, core drill, magnetometer, torsion balance, refraction seismograph, reflection seismograph, gravimeter, various logging devices, *et cetera*. The invention of additional new instruments is not unlikely. But the development of a new geologic tool does not necessarily depend upon the invention of a new instrument. The torsion balance, for example, was not invented specifically for use as a geologic tool. Resourceful geologists made it a geologic tool by using it to determine geologic anomalies.

The geologic data available on a given area may be scant or voluminous, but in the aggregate the amount of information on the geology of the United States jamming the libraries and files of surveys, companies, and individuals is staggering; and the rate at which factual material is furnished by geological and geophysical surveys and wells is no less staggering. Geologists have by no means exhausted the possibilities of making better use of this information in unraveling the geology. Mastery of the various methods of obtaining geologic data is necessary to the understanding of the facts and to the intelligent use of the methods. Referring particularly to the information acquired by geophysical means, geologists can add materially to the interpretations made largely by non-geologists by taking the trouble to learn the principles of the various geophysical methods, and, more important, by working with the data and realizing that they are, in fact, geologic data. Failure to work into the geologic picture this additional geological information is akin to ignoring certain well logs or outcrops in interpreting the geology of an area. If geologists are hesitant to delve into reflection seismograph work, for instance, they need only recall that they use well logs daily and that a reflection seismograph record, like an electric log, is merely a well log expressed in physical, rather than geologic, terms. As a matter of fact, geologists have long used geophysical instruments—the compass, the dip needle, the alidade, the binocular microscope, and the petrographic microscope. Geologists expand their understanding of the composition and structure of a fragment of rock by using the petrographic microscope. By using geophysical instruments they expand their understanding of the composition and structure of what is merely a larger fragment of the earth.

It is realized that not all geologists now have the opportunity of delving into all branches of geoscience, and, further, that there must be specialists in geoscience. Such specialists, many of whom have not been formally trained in geology, have done and will continue to do a most creditable job of acquiring and interpreting new data on the earth. They are indispensable. They can, however, improve their acquaintanceship with the science of geology just as every geologist can strengthen his acquaintanceship with the other geosciences. As geologists and other scientists attain a better understanding of each other's fields, the results of their combined efforts cannot fail to improve. Independent

interpretations of each line of investigation by specialists in each field are important but inadequate. It is definitely necessary to develop an increasing number of geologists capable of interpreting, correlating, and reconciling all earth data in the preparation of a single interpretation of the geology of a given area.

CONTROLLED IMAGINATION

Every geologist knows that information sufficient to solve any sizeable geologic problem is seldom, if ever, available. There are gaps between the geologic facts that can be spanned only by the imagination. Failure to bridge these gaps means failure to draw conclusions, however tentative they may be. And practically all decisions in exploration, ranging from the decision to explore a remote area to the decision to abandon the last well in an exhausted field, are based upon geological conclusions of a tentative nature. These tentative conclusions, or geologic ideas, grease the gears of the exploratory machine. They frequently turn out to be wrong, but without them little is started, little is accomplished.

To bridge the gaps between geologic data by leaps of an imagination under control is to be resourceful. Controlled imagination is not guesswork. It is imagination tempered by experience, knowledge and sound reasoning. Like a muscle it grows through enthusiastic exercise. Imagination plays its greatest role in the early stages of exploration. The choice of areas to work with seismographs or other tools capable of obtaining details of the geology, is ordinarily based upon few facts and much imagination. The geologist whose imagination assists in leading the right tool to the right area has contributed immeasurably to the discovery of oil or gas. The most competent reflection seismograph party can find no prospects if it is always assigned to unpromising areas by those in charge. In the progress of detailed investigations the geologist who detects in the incomplete work a suggestion of an important structural anomaly in an inaccessible area, and proves its existence by going to the trouble and expense of exploring the area in detail, has used his imagination to great advantage. The geologist who daringly places the right geologic interpretation upon a mass of data that the unimaginative are afraid to interpret has also demonstrated the potency of an imagination under control.

It would indeed be a calamity if geologists failed to develop further their imaginations by adopting the false premise that the machines will do their thinking for them. A new machine may make it unnecessary to imagine any longer what certain conditions may be, but each new machine provides geologists with new data upon which to ply their imaginations. The machines merely guide imagination into new channels. Thus, by using the reflection seismograph, geologists may no longer have to imagine what the subsurface may be beneath a surface nosing, but the problem of using the seismograph to the best advantage and of interpreting correctly the seismic data puts as great or greater burden

upon their imaginations. Likewise, in the days before electric logging when faulting was supposed to be extremely rare in the Gulf Coast, geologists did not have to work their imaginations on the solution of complicated fault systems.

Through experience in drawing geologic conclusions from a miscellaneous assortment of data, every geologist has developed to some degree the necessary powers of controlled imagination. Petroleum geologists as a group have matured to the point that their imagination, when under control, is in effect a geologic tool. In investigating the geology of the world for economic purposes, this mental tool must play a part increasing in importance as weaker and weaker geologic evidence must be employed as the basis for interpretations.

CONTROLLED IMAGINATION IN APPLIED GEOLOGY

It need not be pointed out to a group of petroleum geologists that in this highly competitive oil business a constant stream of economic decisions, as well as geologic decisions, must be made based upon whatever geology may be available. Just as the undiscovered reserve is useless unless converted into the discovered reserve, geology is useless to the industry unless it is translated into economics. The petroleum geologist's job is not done when the geologic investigations have been completed; it has just begun. In translating geology into economics, no machine will assist geologists to read into the geology the practical application of it. Geologists have only their experience, knowledge, theories, reasoning powers, and imagination to guide them. In other words, their only tool is the head.

The choice of areas to investigate and the choice of geologic anomalies to drill are two of the most serious economic problems in the search for oil and gas fields. In attempting to solve these problems, geologists draw heavily upon their knowledge of the geology of known oil and gas accumulations. It helps considerably to possess worldwide knowledge. It is not far-fetched to state that a geologist can find more oil in Michigan, for instance, if he understands the geology of the oil deposits of a remote area like Iran. This knowledge of the past, however, is inadequate. Something must be added, and this something springs from the imagination. It takes imagination to apply the one fundamental principle governing the occurrence of oil and gas deposits, namely, that important deposits of oil and gas occur only in traps in permeable rocks in sedimentary sections that are mainly marine in origin. What are traps? They are any kind of geologic anomaly that can hold oil and gas. One cannot forecast accurately the kind of structural anomaly it takes to hold oil and gas in a given area, cannot forecast accurately the underground stratigraphic and structural changes that may form or assist to form a trap, and cannot forecast precisely the probable producing formations. The next great oil or gas field may well be stratigraphically and structurally quite unlike any presently known field. The geologic setting of the next petroliferous province may be most surprising.

The unimaginative appraisal of the economic significance of geology in the

light of the past—orthodox economic appraisal—leads to mental condemnation of those geologic anomalies that are unlike those upon which nearby or remote oil and gas fields are located. The libraries and files of surveys, companies and individuals are full of geologic data indicating a number of good prospects mentally condemned as of this date. Any geologist at any time may see one or more fields or new petroliferous provinces in these libraries or files by the not altogether simple process of tearing himself away from orthodox economic appraisal of the geology and adopting a fresh viewpoint. The more imaginative geologist can achieve this fresh viewpoint; the less imaginative achieve it, if at all, with difficulty.

Most geologists can draw upon their experience and prepare a rather imposing list of oil and gas fields located in areas where oil and gas were not supposed to exist, or located on anomalies known to many but mentally condemned by all but a few or all but one geologist. In attempting to analyze such a list, I reach the conclusion that the geologists responsible for the discoveries had controlled imagination, and pushed the use of it, while their competitors were complacently hiding behind the screen of orthodox economic appraisal, styling themselves practical men. These competitors thought they knew, among other things, that a certain number of feet of closure was necessary, that certain formations could not produce, that a county line or river separated the good and bad areas, that a certain area might produce gas but certainly not oil, and that the rims of certain basins might be good but certainly not the bottoms. In short, they knew where the oil was not, and built mental walls around these supposedly undesirable areas in order to contain their efforts and money in the supposedly desirable areas. The oil finders, recognizing the impractical procedure of applying a little knowledge unimaginatively to the solution of so vast a problem, merely adopted the truly practical procedure of drilling those geologic anomalies which stood the test of their own interpretation of the economic significance of the geology. The oil finders, directing their mental efforts to developing reasons for the presence of oil and gas fields, were positive thinkers. The non-oil finders, directing their mental efforts to developing reasons for the absence of oil and gas fields, were negative thinkers.

SALESMANSHIP

The oil finders do something else. They sell themselves on their interpretations and in turn sell their ideas to others capable of completing the discovery process. The loss of a good idea through poor salesmanship may postpone indefinitely the discovery of an important oil or gas field or new producing province. Salesmanship is the all-important follow-through.

The selling of geologic conclusions of the more imaginative variety admittedly calls for strong salesmanship. The potential buyers are frequently steeped in orthodoxy and inclined to place little trust in projects that depend heavily upon the human equation. Moreover, since geologic conclusions are tentative and subject to rapid change, geologists commonly find themselves in the position of

having to unsell the potential buyer on an idea previously sold to him. The job of unselling is as big as the job of selling. Neither job can be done well if geologists have not translated their geology into economics, the language of the potential buyer. The geologist who understands thoroughly the economic implications of his geology has gone a long way toward selling his ideas, imaginative though they may be.

There is definite need of selling more wildcats in the wide-open spaces where geologic evidence may be thin but where the much-needed new provinces may be waiting to be tapped. There is need for deeper drilling in producing provinces. More effective salesmanship on the drilling of more test wells in the search for stratigraphic traps or in the exploration of complicated structures is a necessity. The industry and geologists should be more widely sold on the idea that the drill is a geologic tool, a tool for gathering geologic information as well as a production tool. The burden of developing and selling an intelligent drilling campaign of the proportions needed rests upon geologists.

CONCLUSION

Resources and resourcefulness. We have them both in quality and quantity. They are equally important as national assets. However blessed our land may be with deposits of oil and gas, they must be captured before they are, in a practical sense, resources. Petroleum geologists lead the way in the initial phase of capture —exploration—and are playing an ever increasingly important role in the succeeding phase—exploitation. It is imperative, therefore, that their resourcefulness, although but one element of the industry's resourcefulness, be maintained at the highest possible levels.

The problems of pure and applied geology will continue to depend heavily upon the imagination for solution after the development of many new fact-finding devices, including those which may detect oil and gas accumulations directly. Hence petroleum geologists have no alternative but to develop further, and to employ fearlessly, controlled imagination in interpreting and applying their science. Furthermore, there is little choice but to be alert to the development of new geologic tools and concepts, to push to the limit the use of old and new tools and concepts, to acquire and apply worldwide knowledge and experience, to think positively rather than negatively, to fuse into all interpretations every scrap of earth data however obtained, and to evaluate thoroughly the economic implications of the geology. By increasing the resolving power of geology through the continuous improvement of geological resourcefulness, a greater and greater percentage of the nation's undiscovered reserve of oil and gas will be captured for the benefit of man.

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EVALUATION OF NEW GEOPHYSICAL METHODS[1]

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INTRODUCTION

Last March when you did me the honor of selecting me as president, I hoped I would have the privilege in my presidential address of telling part of the story of the contributions of geophysicists to the war effort, and of attempting some prophecies concerning the contributions of the war to geophysicists' future prospecting efforts. For a time last fall, official optimism reached the point where it seemed that it would be possible to secure the release of some of the story; however, in December, I realized that someone else would have that pleasure. But, in looking forward to the day when we can turn away from our wartime activities, I have had my interest rekindled in an old problem, a problem which, with our present prospecting organizations, is the mutual responsibility of geophysicists, geologists, and management. It is the problem of evaluating proposed new geophysical prospecting procedures and the somewhat simpler but still extremely difficult problem of evaluating modifications of existing methods.

We all remember the anguished cry that only the widespread adoption of new discovery methods could stop the distressing decline of discovery rate. Yet we know what happened when the problem of inadequate discoveries was made more acute by an unprecedented increase in production to oil the war. The number of seismograph crews reached an all-time high. The number of gravity crews reached an all-time high. But what of the crews using new or unconventional methods? Why are they conspicuous for their rarity? You know the answer. Wisely or foolishly, we were afraid to use them when the heat was on.

I wish that my title, "Evaluation of New Geophysical Methods," actually meant that I was offering an evaluation of a number of new geophysical methods. Unfortunately, at the moment, there is a dearth of proposed methods, sound or unsound. The causes of this scarcity are well known and will end with the war. The unparalleled demand for technical men in the development, design, manufacture, and use of instruments of warfare, has not only drawn the time and thought of nearly all of our research men and many of our operating men but has also turned the attention of free-lance inventors, as well as crackpots, away from the ever-alluring problem of getting rich quick by discovering the answer to the problem of finding oil. This is natural. The problems of war have the obvious appeal of patriotism and, equally important, the stimulus of new and exciting approaches, as typified by radar.

But the war has not dried up the stream of oil-finders' dreams; it has only dammed it up. War has emphasized the vital role petroleum plays in modern life.

[1] Presidential address, Society of Exploration Geophysicists, Tulsa, April 4, 1945. Reprinted by permission from *Geophysics*, Vol. 10, No. 3 (July, 1945).

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Over half of the tonnage of war material shipped overseas is made up of petroleum products. Moreover, the pinch of gasoline and fuel oil rationing in this country has brought the problem home in a very direct and personal way. Everyone knows we must have an abundance of oil. It has also been widely stated that our oil-finding effort is not too satisfactory. Even before the war, we were told by many authorities that our consumption of petroleum was outstripping discoveries at an alarming and rapidly increasing rate. The enormously increased demand for oil brought on by the war and the diversion of the efforts of many men from prospecting, have obviously made the problem even more serious.

It is certain that the rewards, which this situation promises the fortunate inventor, coupled with the availability of wartime technological miracles, such as some of the gadgets which drove the Nazi submarines to cover, radar and other still secret developments, will result in a stream of proposals of new geophysical methods and modifications of old methods. Radar may well replace the witch-hazel fork. When this flood comes, from our own men and from outsiders, we will be faced with a two-fold problem of extraordinary difficulty. First, we must recognize and adopt any proposal of real merit. Second, we must condemn, with the least possible expenditure of money and effort, all proposals which have no real merit.

STATEMENT OF CRITERIA

Here I hasten to make my second confession. Not only have I no new methods to evaluate for you to-day, I also have no sure and simple system of evaluation to propound. I hope, however, that it may prove helpful, or at least interesting, to discuss a few phases of the problem. Let me first state five criteria which a usable geophysical prospecting method must satisfy. I am willing to make the categorical statement that any method which fails to satisfy these criteria, properly interpreted, is of no value. At first sight, these criteria may seem so obvious that discussion is unwarranted. Perhaps. But the first three are fairly simple to apply and will dispose of a high percentage of crackpots. The last two, which are intimately related, are the ones which require skill, patience and a touch of clairvoyance, to apply with certainty.

First, the method must involve physical measurements of some property of the earth. I use the term "physical" here to distinguish from "psychical" and include chemical, biological, and so on.

Second, the measurements must give reproducible results. The term reproducible will require some explanation.

Third, the process must be able to compete, on the basis of economics, with existing methods. This involves both the cost of operations and the value of the results.

Fourth, and this is almost a restatement of our problem—the method must have a significant relation to the occurrence of oil.

Fifth, the method must have a teachable interpretation.

DISCUSSION OF INDIVIDUAL CRITERIA

A consideration of the individual criteria will show that they are somewhat less obvious than appears at first glimpse. The first criterion, that the method be based on physical measurements of some property of the earth, seems one that could cause little argument. I would like to extend this criterion to require that the physical property involved be identifiable. This would, I believe, exclude the wiggle-sticks and unique instruments, which, for reasons unknown to the discoverers, give certain reactions when directly over oil or gas. Even if some Yogi has psychical powers that enable him to locate oil or if by some queer and unknown chain of events, my watch decides to stop whenever I cross a pool of oil, these remain isolated phenomena and unless the laws that govern them can be determined and, in the first case, our seismograph computers taught Yogiism, and, in the second, our instrument makers taught to duplicate my watch, neither can form the basis of a new geophysical method. Under extraordinary conditions we may be willing to waive the requirement that the physical property be identifiable and insist only that a definite series of manipulations leading to a numerical result be followed. We twist the knobs on a little black box according to definite rules and read a scale. If I can be convinced that the resulting scale reading is actually a function of the location where the measurements are made and satisfies my second criterion, I may begrudgingly admit that it is a physical measurement of some as yet unidentified property of the earth, but until I invent a name for the property and discover some of the laws it obeys, I will remain unsatisfied and suspicious.

Suppose now we have a device which gives a physical measurement in this sense. It is of no value unless the elementary data which it gives at a series of stations in an area can be repeated with a sufficiently high degree of accuracy or unless repeatable secondary values can be obtained from these primary data by straightforward computations calling for a minimum of personal judgment. An example of the latter type is given by a magnetometer survey where corrections must be made for diurnal variation. This criterion is not too simple to apply. No physical measurement can be made with absolute accuracy. If enough significant figures are retained, repeated readings will always differ. This is often particularly pronounced in geophysical measurements. We must, therefore, decide what we mean by a sufficiently high degree of accuracy of repeated measurements. The error in repetition at an individual station must be a fairly small fraction of the difference between values at stations on and off of the anomaly. Not only must the measurement at individual stations be reproducible but the anomalies obtained in an area by occupying two different but overlapping sets of stations should practically coincide. The data should be smooth in the sense that the variations observed over an area containing an anomaly interpreted as indicating an oil field, should be much greater than the variations observed when the same number of stations are crowded into any small portion of the area. It is true that a method which is basically sound may fail to meet this criterion in the course of

any one trial because of instrumental difficulties. But this is a problem for the developer of the method, not the evaluator. Until such difficulties are largely overcome or at the very least readily identifiable, the process should not be called a geophysical prospecting method.

With satisfactory coöperation from the advocates of the method, these two criteria can be applied with reasonable assurance that fairly definite answers to them will be obtained without an excessive expenditure of time, money or effort. The principal requirement, other than careful, conscientious work, is that a sufficiently large region be covered to give both normal and anomalous areas. A method which fails to satisfy these two criteria certainly cannot be used as a practical prospecting method; at best, it may serve as the basis for further research. On the other hand, it is easy to think of methods which satisfy these criteria which are not useful prospecting methods. As a concrete example, I can mention measuring the distance to the nearest hard-surfaced road. Incidentally, it might surprise you how well this method succeeds in finding oil fields!

Before we turn to the difficult and somewhat speculative fourth and fifth criteria, let us look at the reasonably simple third criterion—the method must be economically competitive with existing methods. That is, it must give valuable results not given by other methods at comparable cost. This may be true if it finds oil not found by other methods, even though it may fail to find some oil they can find. It is not necessary for a new method to make all existing methods obsolete in order for it to deserve acceptance. Each individual case must be considered on its own merits. We can, however, determine some general limits. The cost per acre certainly must be less than the cost of drilling closely controlled wells to the maximum effective depth of the method and closely enough spaced so that no commercial deposit of oil or gas could be missed. It seems safe to assume that no geophysical method will give more direct and valuable data than a properly drilled wildcat. At the other extreme, a new method cannot compete with one of the established methods which gives equivalent information at a comparable cost per acre. Within these wide limits, the cost and value of the method must be weighed against one another and against those of other methods by intelligent guessing. In many specific cases, there may be room for arguments, but frequently the answer will be obvious after a moderate amount of study.

The fourth criterion, that the method must give information significantly related to the occurrence of oil will in most interesting cases be difficult to apply. I define the term "significantly related" pragmatically. I will say that a method gives information significantly related to the occurrence of oil, if the information is successful in finding oil, when used to guide a program of leasing and drilling with the same intelligence and confidence that the information from reflection seismograph work is now used.

Two approaches to the application of this criterion are useful. The first is the theoretical. If the theory of the method is well developed and if numerical data on the variation of the relevant physical properties on and off of anomolies are

available, it is possible to give a mathematical "Yes" or "No," if the calculations can be carried out without the necessity of introducing approximations which vitiate the conclusions. Three substantial "If's"! Thus, it is possible to say with complete assurance that no refinement of surface gravity methods will permit one to determine the presence or absence of oil in the subsurface. Likewise, it is possible to say that radar methods, depending on the transmission of ultra-high-frequency electromagnetic waves through thousands of feet of soil will not find oil in place. There is, however, a serious danger in theoretical studies of reaching the wrong conclusion by starting from false assumptions. Everyone knows the classic story of the major company that refused to use the reflection seismograph for five years after its introduction because an internationally known physicist, retained by them as a consultant, proved mathematically that the method was unsound. However, even where a final and definite answer can not be obtained from a theoretical investigation of the method, such a study is very useful both in applying the method and in guiding an empirical study by suggesting possible strong and weak points of the method. Whenever possible, it should be part of the evaluation program.

The second approach is the empirical and statistical. A thorough empirical study is a long and costly process. Because of the nature of the technical problems involved, the direct responsibility should be borne by a geophysicist, but because geological data, and often information on future drilling programs, are needed, the geologists are closely involved. Likewise, because the program may well involve very substantial expenditures before a final decision is reached, full support from management is essential.

One of the first and most important steps in an empirical evaluation is the selection of the types of areas and the actual areas to be studied. It is frequently necessary to select a number of different areas for study before condemning a method. Suppose the first tests of the reflection seismograph had been in certain parts of West Texas! Or, suppose the early refraction and gravitational work had not been in salt-dome country! A number of systems for selecting the trial areas has been suggested. A popular and useful system is to select areas where rather comprehensive data, from other geophysical methods and from wells, are already available. This system has the advantage that the results of the proposed method can be compared with those of other methods very quickly. There are, however, some other serious objections to this system. For example, the physical nature of an oil field is changed in many respects during the development process. This may well result in anomalies on the oil fields which were not there before the development. Or, conversely, it may obscure a legitimate anomaly which could readily have been found before development. Nor is this all. The interpreter is very apt to be influenced, one way or the other, by his knowledge that an oil field is there. Even if he is not, any one who examines his work will be inclined to discount the anomalies which occur on oil fields. Thus, both physical and psychological factors conspire to detract from the value of the areas which are occupied by oil fields.

The same thing is true, to a lesser extent, of dry holes. Even if there are no oil fields or dry holes, there is some fear that the results, particularly if an important element of judgment is involved, may somehow be colored by the information already in hand. If an area is selected where little drilling has been done, but where the geophysical data are considered good, useful results are obtained where the new and old data agree; but when they disagree, one is in a dilemma. If the old method is assumed to be perfect, there is little point in trying the new method. But if it is admitted that the old method is fallible, nothing is added to our knowledge of the new method. This system, however, is particularly useful in studying methods for which very specific claims have been made. For example, a method which is supposed to locate the edge of production by measurements along a single profile may be quickly disposed of in the woods on the edge of any one of many oil fields. Or, an electrical method which is said to be insensitive to shallow variations may readily be checked by a line across a known shallow anomaly. Such spot tests are necessarily negative in nature. They weed out some unsound methods but do not prove the soundness of the methods which they fail to condemn. In using spot tests, one runs the risk of condemning a useful method because its promotor was over-enthusiastic.

Another system, which has much to recommend it, is to work fairly large areas around locations of wildcat wells which are to be drilled in the near future. This avoids most of the difficulties of the preceding system. It requires much more time and is therefore feasible only for very promising methods. It may be argued that this system gives some advantage to the method under investigation since wildcats are presumably drilled only in areas which seem favorable. This difficulty can be minimized by working a large enough area round each wildcat.

A third system, which on a purely technical basis is the most desirable but which is very expensive if the method turns out to be unsound, is to select a number of rather large areas, prospect them with the proposed method and then drill the anomalies. This gives a very direct answer as far as each particular area is concerned. A disadvantage of this system is that if the method fails in the first area tried, it is very likely to be condemned even though it might well have succeeded in the next area.

Whatever procedure is used in attempting an empirical evaluation of a proposed method, there is a grave danger of demanding an unnecessary degree of perfection. Because of the limitations of the present prospecting methods, a new method could prove to be very useful and yet have a fairly high ratio of failures to successes. According to Lahee, of 596 wildcats drilled primarily on seismograph data in 1943, only 123 were producers. Thus, a new method, which gave one discovery out of each five wildcats, might be a serious competitor of the seismograph in determining locations of wildcats. This contrasts rather strongly with the scale we are likely to use in evaluating a new method empirically. Depending upon such factors as the "reasonableness" of the method and our personal hunches, we are apt to demand that the method find 75 to 100 per cent of known prospects in an area and that from 50 to 100 per cent of the prospects it finds,

on which we have other information, should be either oil fields or at least suitable traps. On the other hand, if we lower our standards to a somewhat more reasonable ratio of successes to failures we run into trouble with coincidences and the possibility of those secondary factors which result from the development of oil fields, such as my earlier example of hard-surfaced roads.

By my fifth criterion, the method must have a teachable interpretation, I simply mean that it must be possible for a trained interpreter to derive from the primary data, given by the method, information which is usable in the search for oil and that the process used in deriving this information must be one which may require intelligence, experience, and judgment but not guesses or arbitrary choices. Two skilled interpreters should usually arrive at very similar answers. While I have placed this criterion fifth, it is so intimately tied in with the fourth, that the two must be studied simultaneously. An interpretation which satisfies this criterion will very likely combine an application of the theory of the method with geological knowledge concerning the nature of the probable oil traps in the region under investigation. This is not absolutely necessary. The interpretation may be based entirely on an empirical correlation between certain observed phenomena and the occurrence of oil. But such interpretations are usually unsatisfying because they frequently involve too strong an element of personal judgment or even intuition and because it is difficult to amass sufficient trustworthy data to substantiate the correlation.

CONCLUSIONS

My principal desire in this discussion has been to call your attention to the difficulty of the problems involved in evaluating a proposed geophysical method. I hope I have made it clear that this is a problem which demands the most careful and thoughtful attention. It is a problem that can be solved correctly only by teamwork between geophysicist, geologist, and management. Each must contribute his full share and have his full responsibility. The contact between the members of the team must be intimate and each must have the confidence of the others. This is not a problem which can be solved by the haphazard methods that have been used in the past. Nor is it a problem that can be solved by oratory or debate. Unless you are prepared to spend the time and money justified by the worth of a new prospecting tool, you will do yourself a service by not wasting your money and effort and the industry a service by not confusing the picture.

In conclusion, I wish to make it clear that while my topic has called for emphasis on possible new methods, I am neither too optimistic about their possibilities nor too pessimistic concerning the remaining possibilities of our present methods. I expect considerable improvement in our conventional instruments and techniques. But let me close with a word of warning: the future progress of geophysics can not come entirely from technical advances, either in new methods or improvements of old methods. Much of it must come from advances in the use of the minds of geophysicists.

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ROLE OF STRATIGRAPHY IN OIL DISCOVERY[1]

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I. INTRODUCTION

It is a refreshing and profitable undertaking to review from time to time the basic principles on which we work. Such meditation has a salutary effect in any case. If it finds no weakness in our armour we may take comfort; if there are features of which we are uncertain it is important to face up to these and see how they can be remedied. The writer does not claim to be in any way the most suitable person to carry out such a review; all that he can offer is a deep appreciation of the great progress in petroleum geology particularly in the American fields and perhaps a certain detachment from the day-to-day problems which is of value for balanced judgment.

We can all take pride in the fact that geology has achieved its greatest justification as an applied science in its application to the problems of the oil and gas industry. These problems are becoming ever more complex and therefore we must see that every resource of our science is utilized to the full in the problems of oil discovery and development. For the moment our attention is restricted to the problems of oil and gas discovery. In this field geology has taken its rightful place as the foundation of the main principles guiding the search for oil, and whatever new tools may be discovered by our sister sciences, their application to this problem must always be guided by geological principles.

Geologists have broadened and elaborated their theories of oil and gas accumulation as a direct method of finding oil, and both geology and geophysics are primarily concerned in the discovery of structural traps as the most direct approach to this problem. However there are many oil fields which are not due to structural traps and furthermore there are few pools whose position and boundaries are not greatly influenced by stratigraphic features. It has long been realized that the structural theories are only a part of the story of oil accumulation. What the writer wishes to emphasize is that before these structural theories can legitimately be applied there are other stratigraphic requirements which must be fulfilled if the sediments are to be oil bearing. That these stratigraphic considerations are not made in every survey is because most of these surveys are localized in areas where the stratigraphic features are known to be favorable. All petroleum provinces represent such areas, but even a cursory study of their boundaries will show that their limits are more often than not decided by stratigraphy rather than structure. The daily task of the exploration geologist may be concerned so much with structural issues that he can easily get a distorted view of their importance. Yet, if he stops to think, every structural feature which he discovers is part of a stratigraphic story and is permeated with stratigraphic problems.

An oil pool is an incident in the life history of a cycle of sedimentation.

[1] Address delivered at a dinner at the Tulsa Club, thirtieth annual meeting of the Association, March 27, 1945.

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Every large basin of marine deposition is liable to contain many such incidents. They are conceived when source rocks are laid down. They grow and take shape in the oil and gas pools as the source rocks give up their oil and gas to the reservoirs. They die when nature interposes her breaks between the sedimentary cycles and deposition is replaced by erosion. All of the oil pools formed in these cycles of deposition are not destroyed, particularly when the sediments are thick and contain impervious layers. These are the pools which are preserved for the use of man.

In the early stages of exploration of any new area the stratigraphic features are of extreme importance, for it is they which are in the main decisive as to the general importance of the area and the distribution of the main body of pools. There usually ensues a period of what may be termed "structure hunting" when geologists and geophysicists are using geological theories of structural accumulation as a short cut to find those pools which are influenced partly or mainly by geological structure. None the less, these pools do not exhaust the region and inevitably the geologist must return to his stratigraphic studies or the wildcatter must pinpoint the area with a sufficient density of wells if all the stratigraphic pools are to be discovered. It is the writer's contention that this over-emphasis of structure in the middle period of discovery is harmful. It blurs the importance of stratigraphy and therefore leads to the neglect of vital information. It tends to an over-simplification of the evidence in structural pools and it often leads to the abandonment of areas which still have considerable possibilities.

It may be convenient but it is certainly not scientific to concentrate attention on one factor alone when looking for oil and gas, and it is with a view to introducing some measure of a corrective tendency that the writer ventures to stress the importance of the stratigraphic features in a full campaign of oil and gas discovery. An oil pool is an integral part of the stratigraphic history of the sedimentary basin in which it is formed. Its characteristics are determined by factors within the sediments. How therefore can we, as geologists, expect to maintain our efficiency in oil discovery if we fail to make full use of stratigraphy in all stages of the search for oil? Many an area which has failed to yield oil can be shown to be disappointing not for lack of structure but because of its stratigraphy. Used therefore as a positive means of directing attention to the most likely territory, or as a negative feature in warning of the unfavorable conditions in a particular area, stratigraphy is the foundation of the geologist's evaluation of any general region. He may also use other tools for discovery but he must inevitably return to his stratigraphic considerations as soon as his problem becomes complex. The geophysicist can sometimes afford to neglect geological advice when dealing with an area where all the stratigraphic features are favorable. He would inevitably go completely astray in forming an opinion without geological evidence and advice where the stratigraphic features are complex.

2. STRATIGRAPHY AND SOURCE ROCKS

Stratigraphy in its broadest sense is the history of the earth as written in the strata. Like the records of early human history the story is never complete but

from the point of view of the oil geologist the records are usually available for the periods when the oil-pools are being formed. They are scanty and incomplete for the time intervals when oil and gas are being dispersed. The formative phases of an oil pool can be conveniently divided into two stages, both of which are a part of the stratigraphic history of the sedimentary basins. The deposition of the source sediments and the formation of the oil and gas determines the general boundaries of the petroleum province. It is the controlling factor which must intervene before oil pools can be formed. The second stage of the life cycle is the formation and growth of the individual pools. It is part of the absorbingly interesting but much neglected history of the sediments after they are laid down and is associated with the fluid movements of water, oil and gas as the strata become compressed.

The stages of growth of an oil pool may be simple or complex. They may occur at one general geological period or they may be repeated at different time intervals by recurrence or readjustments of the fluid movements guided by the physical characteristics and the form of the strata.

Dealing in the first instance with the inception of the petroleum provinces, it is now generally admitted that oil and gas are, in the main, formed within sediments of a marine type and they they are produced from the organic matter distributed through the strata. How, when and why the oil and gas are formed are subjects on which there is a great diversity of opinion. The answers may not appear vital to our present considerations but they are certainly necessary if we are to pursue the task of oil discovery with a clear conception of the problems involved. The rocks in which the oil is originally generated, i.e., the source rocks, whether they be clays, marls or limestones, obtain their organic matter from the sea or from the neighboring land masses. The types of environment in which this organic matter can be deposited within the sediments becomes therefore the first goal of the stratigrapher who is attempting to determine the boundaries of an area in which oil and gas may be anticipated.

The problem of the source rocks is therefore intimately bound up with the problem of the origin of oil. In certain senses the two are one problem, but whereas oil can be formed in many different ways, the selection of the procedure which nature follows is limited by the consideration that it must be one to which the source rocks have been subjected. They themselves have a history, and that history forms the first test to which every theory of the origin of oil must conform. For this reason the origin of oil is essentially a geological problem and can only be finally solved on the evidence which stratigraphy produces. This does not mean that the help of the chemist, biochemist and biologist is not needed in the investigation, it is in fact essential to the task, but the problem will never be solved until the pool of evidence produced by all methods of attack is sifted and selected to conform with the stratigraphic evidence.

It is unfortunately true that too little attention has been paid in the past to the identification and study of the source rocks in each petroleum province. In

many areas we are still uncertain of the identity of the mother rock from which the oil has been derived, and because these studies have been neglected, our knowledge of the limits of the petroleum provinces lacks something of the precision which this evidence would have supplied. Few geologists would deny that if we could establish our source rocks and knew more about their supply of organic matter, the environment in which they were deposited and the critical conditions which cause the oil to be formed we should be a long way on the road to a complete study of our petroleum provinces. This study is not of mere academic interest. It is of fundamental importance that our strategy of oil discovery should neglect no line of evidence which has a direct bearing on its problems. Rather may we admit that in concentrating too exclusively on the structural theories of accumulation geologists have strayed into a single easy avenue of approach rather than view the problem as a whole. At some period the question is bound to arise whether each area has been exhausted. The answer can only be either by exhaustive and expensive drilling or by the evidence which stratigraphy can give. Among this evidence, the extent and richness of the available source rocks are bound to be of primary importance. Whilst therefore we are drilling up the potential oil and gas areas, it is important that attention should not be focused too exclusively on the potential reservoir rocks, a practice all too common nowadays, for there exists in the associated strata a rich field of evidence whose value we must not underrate. For the same reason we must remember that in abandoning the more tedious and protracted petrological examination of well samples and the biological evidence they afford for the simpler, more complete but stereotyped physical record which the Schlumberger survey provides, we are gaining perhaps in the ease of our correlation but we are losing substantially in other lines of evidence which we cannot afford to discard. We have still too much to learn of the life history of petroleum to be too exclusive in our methods of search. The only safe approach is to study all those factors which have a bearing on the subject and among them the problem of the source rocks is not only the first but it is of fundamental importance.

There arises on the boundaries of every sedimentary basin a limit where the source rocks must cease to function. Usually the potential area of source rocks is considerably less than the area of the basin, though it may be and usually is much greater than the extent of individual reservoir rocks. The stratigraphic reasons for the absence of effective source rocks may be varied. They may never have been deposited, or if deposited their richness in organic matter may be too low, or the environment of deposition may have so changed that their organic content has completely disappeared. All these possibilities have a stratigraphic significance and if we were cognizant of them we could take them into account in the search for oil and gas. It is therefore of fundamental importance that we must learn: firstly, the environments in which source rocks are laid down; secondly, whether there is an effective lower limit in organic content below which a source rock will not yield up oil to the reservoir; thirdly, whether this lower limit

depends on the nature of the source rocks and the degree of the compaction; fourthly, when and how is the oil and gas formed in the source rocks; and lastly, why and when does the oil leave the source rock for the reservoir rock and can this process of migration be repeated at successive stages in the history of sedimentation.

The question whether there is a lower limit of richness in organic content below which a source rock becomes ineffective is one of the fundamental issues in the study of source rocks. In the early days geologists were prone to regard source rocks as freak deposits of rich organic content. The tendency nowadays is to go to the other extreme and dismiss the problem of source rocks as immaterial on the assumption that almost all marine areas will provide such types of strata. Certainly experience has shown that the earlier view was too exclusive but the writer would still claim that the general geological evidence and the physical behaviour of the clays and marls under compression supports the view that in general source rocks must reach a certain limit of oil content before they will readily yield up oil to the reservoir; or perhaps it would be more true to say that clay rocks will retain considerable portions of their oil content dependent on the degree of compaction to which they have been subjected. It is this feature more probably than any other that is responsible for the phenomena of secondary enrichment in oil which have been postulated in certain of our oil pools.

The problem of the time interval during or after sedimentation necessary for the conversion of the organic material to oil is bound up with the *modus operandi* of the operation. Is oil formed during sedimentation or is the organic change due to later influences? This problem is fundamental to the whole question of oil migration and its solution would throw a flood of light on many of our problems of structural accumulation. There must exist a large amount of stratigraphic information on the time when the first recognizable movement of oil in the strata can be noted and it is curious that this has not received more attention in the literature. Certain it is that in Trinidad, for instance, the evidence of mud flows due to oil and gas was pene contemporaneous with the upper zones of the oil-bearing strata. If therefore the oil and gas was indigenous to these Miocene formations they must have been formed from the organic matter during the cycle of deposition of the Miocene. Again reverting to the same area it is clear that in the southern oil-bearing portion of the island the stratigraphic change from marine to deltaic and fresh-water conditions determines the normal upper limit of the oil-bearing strata. Furthermore as the latter are traced northwards across the island, facies changes in the formations are intense. There appears to be considerable evidence that these facies changes play a part in determining the presence of oil, though more evidence will be needed before the picture becomes clear. It is such stratigraphic studies as these that are required if the geologist is to be fully equipped for the search for oil and gas and, whilst the writer does not deny the immense value of the structural theories as an effective and rapid approach to the problem, he does contend that if by too exclusive a use of this method of attack

we weaken our study of the fundamental stratigraphic problems, we are likely to lose thereby, particularly in the later phases of exploration.

3. STRATIGRAPHY AND RESERVOIR ROCKS

The importance of stratigraphic factors in determining the position of some of our most important fields and the influences of the condition of deposition on the shape and characteristics of the reservoir rocks has received so much attention that it is not necessary to stress this factor to any degree. Fields like East Texas point the moral even to those who will only take a superficial view. Those, however, who are prepared to look below the surface realize fully that from the earliest history of oil, beginning with the developments in Pennsylvania, stratigraphic factors have played a vital part in all oil fields even in those which to the superficial observer seem ascribable entirely to structure. One has only to examine in detail the behaviour of oil and gas in fields all over the world to realize that the petrographic characteristics of the reservoir are so important that often they dominate all other features, even including that of structure. It is unfortunately true that these petrographic characteristics cannot be prophesied at the surface and until the drilling record becomes available there is no means whereby these features can be used as a direct means of searching for oil. The result is that fields which are discovered on structural hypotheses tend to have their stratigraphic peculiarities overlooked even when the latter become clear in the process of development. An isolated lens field discovered on an anticline would almost certainly be ascribed to the anticlinal hypothesis. Only when such a lens was discovered by a chance wild cat well far down flank or in the heart of a syncline would it receive its true explanation as a stratigraphic trap.

Most of the structural theories depend for their validity on the ability of oil and gas to migrate with considerable freedom. Unless this can take place the value of the structures as traps cannot come into play. Therefore it is generally true that for any particular structure to perform its function as an oil trap the carrier or reservoir rocks, i.e., the portion of the sedimentary succession with sufficient permeability to allow free lateral differentiation of gas, oil and water must extend over and beyond the limits of the structure. In Pennsylvania, for instance, the general structure is a large regional syncline. We do not however regard the individual pools as examples of oil accumulated in a syncline because the actual reservoirs are only small segments of the sand sheets and also even the latter do not extend over the whole limbs of the regional syncline. Where, however, we are dealing with large folds and reservoir rocks whose lateral extent is limited by the conditions of sedimentation, and where the reservoir rocks are small in regard to the wave lengths of the folds, there is no apparent reason why a lens within a syncline should not be as rich in oil and gas as one within an anticline. The respective economic value of the two would be determined more by the depth of drilling and the thickness of oil-bearing rocks than by their position on the structure.

In Trinidad, for instance, the producing areas in the southwest of the island are limited to those regions where the Forest, Cruse and deeper formations contain sands. As these sands are traced in a general northeasterly direction they diminish rapidly and the structures which in the west carry oil in commercial quantity become valueless towards the east because of the lack of developments of sand reservoirs. Such cases are well known in fields all over the world. They are so self-evident to the geologist that he often fails to stress their significance not because he does not appreciate the problem, but as it is constantly with him he unwittingly fails to differentiate the importance of stratigraphy as contrasted with structure in his considerations. In Trinidad for instance there can be no doubt of the importance of the anticlinal theory. It functions wherever there are sand reservoirs of suitable extent which will allow the anticlinal theory free play, but it will not function without the sands and although most of the wells on the island have been located on structural grounds, their success or failure has usually been determined mainly by stratigraphic factors. There are many areas in the island where structural conditions are highly favorable but where on account of the paucity of sand reservoirs drilling results have been uniformly unfavorable. It would be difficult indeed to make a fair assessment of the relative value of anticlincal accumulation, fault blocking and sand distribution in relationship to the field developments and exploratory drilling in the island of Trinidad. Certain it is that no geologist who did not take all three into consideration in his drilling program would be looking for trouble. In such areas as these mere determination of structure either by geology or geophysics would be a very partial and expensive method of exploration.

Stratigraphy, it was explained above, is the record of past conditions in the strata. As such the significance of the reservoir rocks is usually as a record of littoral deposition, beach conditions, *et cetera*, or of the moving bodies of water such as marine currents which can carry sands considerable distances over the continental shelf and deposit them in ribbons and lenses over the ocean floor. The position of the strand lines and also of the ocean currents must vary considerably as diastrophism alters the distribution of land and sea in time. Once an area has been studied in detail and a knowledge of its sediments has been accumulated it is possible for the geologist to trace the general distribution of the reservoir rocks in time and space, and no matter how much he may use local structure as a guide to drilling he must also use his stratigraphic knowledge as a general framework for his policy of exploration. Certain areas will be drilled to specific stratigraphic horizons because suitable reservoirs can be expected within them. Local structures it is true may guide the final location of the exploratory well, but the reverse is also true; all the structures in existence become valueless unless there are reservoir rocks within the strata below the surface.

One of the many concerns of stratigraphy is the study of the past distribution of land and sea and the changes in the conditions within the sedimentary basins

as diastrophic movements produce transgressions and regressions in the same general areas. Such movements of the strand lines are one of the most important studies in determining the zones where overlapped sand beaches and sand bars are likely to be included in the succession. The belts over which these movements take place and the zones adjacent to buried ridges on the sea floor are normally the most favorable zones for reservoir rock formation and the guidance of geology is required in determining where these zones are prone to occur at various stages in the geological column. This is but one illustration of the importance of stratigraphic studies and the lesson to be learned is that no effort should be spared to have our stratigraphic information complete if it is to play its full part in the discovery of oil pools. The importance of these considerations do not need further emphasis in the oil literature of America where attention has already been drawn to these possibilities by a number of prolific oil fields and by the admirable studies of men like Levorsen of this particular angle of the problem.

4. STRATIGRAPHY AND OIL PRESERVATION

It will be readily admitted by oil geologists that we have tended in the past to take too restricted a view of the areas in which oil can be discovered. It seems probable that oil is generated as a normal material in marine sediments on parts of the continental shelf and of the main marine basins. Certainly few geologists would hesitate to drill in any area which contained a reasonable thickness of marine sedimentary rocks provided he was satisfied that such rocks contained a certain percentage of permeable strata. This being so it is not at all clear why oil in commercial quantities is not more widespread. Large areas of the sedimentary basins have so far failed to yield oil in quantity. In fact the area of productive oil pools is but a minute fraction of the total area covered by marine sediments. If therefore we agree that source rocks are in fact a normal accompaniment of marine sedimentation, why are not oil fields more widespread?

The answer to this question is in the first case that a commercial oil pool requires more than oil source rocks alone; it requires the association of both source and reservoir rocks and, furthermore, it needs the proper conditions to ensure that oil and gas pools when formed are protected from dispersion. It is to this feature, the natural dispersion of oil pools, that our attention is now directed and it is emphasized that the preservation of oil and gas is a matter which requires conditions just as specialized as those which ensure the formation of the pools.

Oil-field experience emphasizes the fact that oil seepages, which are examples of natural leakage, are more extensive and spectacular among the younger formations than among the older. It would be untrue to state that seepages do not occur in the older rocks, but they rarely reach the dimensions of those commonly found in Tertiary fields. In general the latter occur in the more disturbed zones of tectonics and it may well be that the high degree of leakage is significant of the deformation rather than the age. None the less we may also draw the conclusion

that where the older rocks are highly disturbed the rate of leakage has also been high, so that, except where such old rocks have been blanketed by young or impervious formations, all the oil has usually been lost.

Two other features of general experience tend to support this point of view. In general the rate of pressure increase with depth is more rapid in younger fields than in the older. Also there is the general fact that the amount of oil found in the first thousand feet of drilling among the oil fields of the world is very much less than that found in successive thousands of feet at greater depths. A parallel line of investigation into the salt waters of oil fields notes that in general the shallow fields tend to have diluted and mixed saline solutions indicating a considerable degree of dilution of the original connate water by extraneous meteoric waters. Such water circulation takes place as soon as the sedimentary basins are subjected to erosion and as denudation bites more thoroughly into the successively deeper strata. Movements of water thereby induced tend to unlock the gas and oil pools by introducing fluid movement within the reservoir rocks. That this process is not more extensive is due in general to the limited extent of many of the reservoir rocks and to the blanketing effect of younger sediments which often effectively mask deeper formations from water circulation.

The evidence of oil field conditions tends to show that oil and gas are lost from the strata long before the strata are actually uncovered and that one of the inevitable accompaniments of denudation is the impact of circulation within the more porous strata which effectively disperses oil and gas. Such conditions are bound to occur, for a buried pool can be regarded as merely a zone of buried pressure. This pressure is related to the rock pressures when the sedimentary cover is thick. If later on much of this cover is removed, the pressures become out of balance with other fluid contents in the rocks and movement is bound to take place. Now oil and gas movement like any other fluid movement will depend on the permeability of the rocks. In this case it is the impermeability of the cap rocks which has imprisoned the oil and gas, but if this impermeability is destroyed the oil and gas will escape. Earth movements as a whole may in the first instance increase the sealing effect of the overlying strata by increasing their compaction, but if the movements are intensified until the rocks become solidified and then disrupted, the fissuring so formed usually unseals the reservoirs. Furthermore the strong folding of strata, tending as it does to form mountain ranges and foothills, leads automatically to a deeper and more rapid denudation which increases water circulation within the rocks. For both these reasons, therefore, diastrophism generally hastens the process of oil dispersion.

The stratigraphic record is normally made up of periods of sedimentation separated by periods of diastrophism and erosion. In the first the oil is formed and entombed; in the second it is subjected to movement and may eventually be lost. The loss depends on the intensity of the erosion, i.e., the strength of the diastrophic period, and the length of time and intensity of denudation before the next sediments were laid down. Thus in any given area the prospects of finding

oil within a particular formation do not depend solely on whether this formation contains source and reservoir rocks. It also depends on the rhythm of diastrophism, erosion and subsequent deposition to which the area has been subjected since the first formation of the oil pools. If on balance the protective influence of sedimentation has been too strong for the dispersive influences of denudation then the fields will be preserved unimpaired, but if at any period denudation is able to release the oil and gas, no worthwhile oil pools are likely to be found, unless there ensues a subsequent period of oil enrichment due to a recrudescence of the migrating fluids caused by renewed compaction of the deeper source rocks. The gist of these remarks is that the prospects of finding oil in any given area do not depend solely on whether that area has been endowed with oil fields but whether these have been subsequently preserved from eorsional forces which will come into play as soon as any sedimentary basin is turned into a land area or even emerges above the profile of equilibrium. Thus the oil prospects of a given area depend largely on its stratigraphic history and in assessing its prospects it is insufficient to regard only the periods of deposition. They are only the formative periods. A clear picture must also be formed of the erosional epochs and of the chances of survival of the oil pools, bearing in mind the deformation of the strata, the degree of erosion and the subsequent blanketing by impervious rocks. These factors after all constitute a careful study of the stratigraphic history.

If the oil fields and also the areas which are barren of oil are considered in any country, it will be found that the reasons why many areas are non-producing are not always the same. Some regions are non-productive because they contain no source rocks; some because reservoir rocks are absent, whilst many which have both source and reservoir rocks are still found to have little or no oil because denudation has led to its dispersion. In general it will be found that strongly deformed strata of any age rarely contain oil in large quantities unless such deformation is very recent or there has been a thick zone of impervious rock involved in the movement or laid down subsequently. Even a moderately strong deformation is uncommon amongst the Palaeozoic oil fields unless there has been a good cover. Most of the folded oil fields of the world occur among the younger rocks. On the other hand the less folded areas of the world can and do contain both oil and gas whatever the age of the strata, although it is true that such unfolded strata have been more extensively drilled in the United States than in any other region.

It is useful for purposes of comparison to consider the two continents of North America and Europe. The former has had a comparatively tranquil geological history with strong folding only in well defined and strictly limited belts. Large areas have been epicontinental basins of deposition in which sedimentation, though not continuous, has on the whole been the dominant factor. Such areas are favorable for oil and in them the U.S.A. has found its most prolific oil fields. On the other hand Europe, apart from Russia, has been intersected so completely by past folding movements and subsequent denudation that the chances of oil

survival among the older rocks has been small. Almost all its proven oil fields are among the younger formations where erosion has not yet succeeded in dispersing the oil. It is true that there are small areas where Mesozoic and deeper oil have been preserved, but as a whole the areas where this has taken place can not compare with the broad, gently warped basins of the U.S.A.

It is not always realized by American geologists how generously they have been treated by nature in this respect. The lack of success in finding oil more generally in Europe is not entirely due to an absence of effort; it is because in most of the areas the prospects assessed on sound geological principles are poor. One could with equal justice assert that large areas of the U.S.A. have not been adequately drilled and that when they are so, their value will be found to be as great as the areas already developed. This may be partially true, in which case the future prospects of discovery of oil in the U.S.A. are very rosy indeed for there are vast areas of sedimentation on the American continent which are practically untested. None the less the oil fraternity as a whole obviously does not rate their prospects highly or it would not so consistently reserve the major portion of its exploratory effort to the neighborhood of those areas which are already proven. The dictum that oil is found whenever it is drilled for assiduously may have a substratum of truth but it cannot be accepted literally, nor does the history of the American oil effort support the claim. Experience has canalized drilling into certain well defined zones. On the other hand the dictum is true to this extent, that only courage, tenacity and hard work could have built the American oil industry to its present preëminence, and these virtues the American oil man has in abundance. Foolhardiness however and wasteful drilling, which are synonyms for the selection of the most doubtful and improbable areas to test, are not characteristic of the modern oil industry though they will be found in small quantities everywhere. Large areas have been left undrilled even in the United States because their sedimentary history, i.e., their stratigraphy, indicates that their prospects are poor. For the same reason a still larger proportion of Europe is unlikely ever to repay the search.

One of the most interesting examples of oil exploration of recent years has been that of Great Britain. It really began after the last World War but was renewed before the present war by prospect drilling in the Mesozoic formations. The tests of these areas proved, however, unpromising and search then proceeded mainly into the Carboniferous formations on the grounds that the oil shows in these rocks were widespread and that source and reservoir rocks were abundantly present. Small quantities of oil were discovered in the Carboniferous even in the last century, but this recent drilling campaign based on extensive geological and geophysical work has now proceeded a very considerable way. The drilling density of wells in Great Britain does not of course compare with the developed fields of the U.S.A. and it might be contended that it is still premature for us to judge results. None the less it can be stated that the drilling, which has been concentrated in the most likely areas and has been carefully and scientifi-

cally controlled has yielded results, which, to date tend to indicate that post-Carboniferous and pre-Jurassic denudation has largely bled the oil from the potential reservoirs. The fields so far found have been small, pressures low and the inference to be drawn is not that there have not been very considerable oil pools in the area in the past, but that they have been dispersed during an intervening and long past era of denudation. It may still be true that some portions of the east of England may be discovered where protection from this dispersion was more effective, but unless these are discovered it seems on present evidence that the oil fields of England have drastically suffered from their past geological history. This is one of those examples where the prospects of an area are not easy to sum up. Viewed in the light of their oil indications the prospects are considerable. Viewed also in the light of the strata and the structures available, the prospects are good. But reviewed in the light of their full geological history, the prospects are dependent on the degree of denudation to which the oil pools have been subjected in past geological periods. In regard to these prospects there was always room for a very considerable divergence of opinion so far as Great Britain was concerned. The example of England is one which the writer would regard as exemplifying the stratigraphic method of summing up the prospects of an area and among the older formations it becomes, in most cases, the most important part of an oil investigation.

The writer holds the view that source rocks are a normal accompaniment to most areas of marine sedimentation and that oil pools are formed in nature not as some freakish and unusual event, but as the common and logical result of marine deposition. What however is not so common is for such pools to be preserved over long geological periods. There is no difficulty about the preservation of oil and gas in large basins of prolonged deposition, particularly when these are young, but the older sedimentary basins require specialized conditions for protection particularly when they are subjected to diastrophism.

A study of even so favorable an area as the U.S.A. tends to suggest that there must have been very considerable loss of oil in the past. Palaeogeological studies indicate that periods of erosion must have removed large volumes of sediments, many of which certainly contained oil, and it cannot be doubted that in this denudation much oil was bled from the sediments even if the latter were not bodily removed. An interesting though of course entirely hypothetical computation, based on plausible assumptions which can only be approximate but which on the other hand may well be unduly conservative, would tend to suggest that the oil dispersed by nature in past geological time is incomparably greater than that which is preserved. Assuming that in the past practically every portion of the United States has at one time or another been favorable for the deposition of source rocks, a not unlikely assumption, and granting that in these processes of deposition 100 feet of source rock containing $\frac{1}{2}$ per cent of oil by weight were produced, then the volume of source rocks so deposited approximates 60,000 cubic miles and the amount of oil formed is 600 cubic miles. Oil production from

the United States up to the present has been approximately 1 cubic mile and there is an additional amount of slightly less than 1 cubic mile of proven reserves. Assuming an overall 20 per cent extraction these 2 cubic miles of oil account for approximately 10 cubic miles of oil underground. If we double this figure on the assumption that only one half the oil reserves have so far been discovered, the amount of oil accounted for is still only 20 cubic miles, i.e., approximately 3 to 4 per cent of the amount of oil which may reasonably be considered to have been formed. Admittedly gas has not been considered in this argument and if necessary the figures should be enlarged to include the gas reserve. However whilst these figures are only hypothetical and must not be accepted literally, the conclusion seems reasonable that the amount of oil accounted for in the United States, plus the reserves considered possible by oil geologists, would still only represent a small fraction of the oil which on geological principles can be regarded as having been formed in the U.S.A. in past geological periods. A similar comparison in areas like Great Britain would produce figures which are still more striking. We have reasons to believe that a very considerable thickness of source rock were laid down in Great Britain and the small amount of oil so far discovered represents less than .01 per cent of the amount of oil which was probably produced by nature in past geological times.

There can be only three possible explanations of this divergence between oil accounted for and presumptive oil formed: firstly, that the oil reserves are still greatly underestimated; secondly, that much of the oil formed is still within the source rocks and therefore is unavailable; and thirdly, that most of the accumulated oil has been lost by natural dispersion. The first alternative is possibly valid to some extent, but hardly sufficient to be the true explanation. The answer probably lies between the second and the third alternative. Much of the oil formed is probably still adsorbed or absorbed in the clay strata. Research is needed to clear up this issue and to discover what is the maximum percentage of oil that can be so retained. On the other hand there can be little doubt from the behaviour of oil in nature that the most likely explanation of the disparity lies in the dispersion of oil over long geological periods due to recrudescence of the migration currents during periods of denudation.

In areas of continuous deposition these dispersionary migration tendencies can be neglected, for the cloak of sediments prevents general leakage. Where however periods of denudation break the sedimentary cycles much oil is lost and that which survives usually owes its preservation to purely local features.

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SUBSURFACE STRATIGRAPHY OF ATLANTIC COASTAL PLAIN BETWEEN NEW JERSEY AND GEORGIA[1]

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ABSTRACT

Logs and samples from 190 wells located along the Atlantic Coastal Plain between New Jersey and Georgia have been studied. For comparison the records of a few additional wells in Alabama and Florida have been studied. Particular attention has been paid to the macrofossils (especially mollusks) and an attempt has been made to establish the correlation of the subsurface formations. A series of cross sections is presented as well as a correlation chart of the Coastal Plain formations, Cretaceous to Pleistocene, and a map showing the approximate configuration of the basement rock. This study has shown the presence of several formations in the subsurface, not known from outcrops in the region, and has extended the range of others.

INTRODUCTION

This report discusses the subsurface stratigraphy of the Atlantic Coastal Plain between New Jersey and Georgia. This is done by means of a study of well samples. For the sake of comparison a few wells in Florida and Alabama are recorded, but no attempt is made to discuss in detail the subsurface stratigraphy of these states.

Emphasis has been laid on the macrofossils, especially mollusks, and a separate report, to be submitted to the *Journal of Paleontology*, will discuss the significant species found in these wells. However, all available evidence has been used in the interpretation of the well logs and in the separation of the subsurface formations. This evidence includes data on the microfossils where available, the lithology, and a survey of previous reports. Where the correlations are based wholly or in part on the work of others, due credit and references are given in the text.

ACKNOWLEDGMENTS

This study was aided by a grant from the Penrose Bequest of the Geological Society of America, and it is a pleasure to express sincere thanks to the Society for making this work possible. The present manuscript has been released by the Geological Society for publication by the American Association of Petroleum Geologists. Another grant from the Johnson Fund of the American Philosophical Society made possible certain correlative studies on Tertiary faunas on the East Coast, and thus aided the preparation of this report.

The Academy of Natural Sciences of Philadelphia placed all its facilities at the disposal of the writer. Especially useful in this connection was the Lewis Woolman Collection of well samples, mostly from East Coast drillings between 1890 and 1902, now a part of the department of geology and paleontology of the Academy.

[1] Manuscript received, January 3, 1945.

[2] Associate curator of geology and paleontology, Academy of Natural Sciences.

Coöperative arrangements were made with the various State geological surveys between New Jersey and Florida as well as with the United States Geological Survey, particularly the Ground-Water Division. For this latter coöperation the writer is indebted to J. B. Reeside, Jr., and V. T. Stringfield.

The ground-water programs in coöperation between the United States Geological Survey and the State surveys have been the main source of the samples examined during this project. Well samples were examined in the offices of the State geological surveys and many were shipped to Philadelphia for further study. Full sets of samples have in most cases been retained by the Surveys, while some duplicate cuts are on file at the Academy. The location of the various samples is indicated after the discussion of each well. Certain specimens of macrofossils have been deposited at the Academy by the various State surveys.

The following are the main sources of the material examined.

New Jersey: Meredith E. Johnson, State geologist, Trenton
Virginia: D. J. Cederstrom, United States Geological Survey, Virginia Geological Survey, Charlottesville
North Carolina: M. J. Mundorff, United States Geological Survey, North Carolina Geological Survey, Raleigh
Georgia: Garland Peyton and A. S. Furcron, Department of Mines, Mining and Geology, Atlanta; Stephen Herrick, United States Geological Survey, Atlanta; M. A. Warren, United States Geological Survey, Savannah
Florida: Herman Gunter, State geologist, Tallahassee; G. G. Parker, United States Geological Survey, Miami
Alabama: Winne McGlamery, State paleontologist, Alabama Geological Survey, Tuscaloosa

In addition, various miscellaneous samples have been received from the following: Layne Atlantic Company, Norfolk, Virginia; Artesian Well Drilling Company, Philadelphia, Pennsylvania; N. Shannahan, St. Michaels, Maryland; Willard Berry, Duke University, Durham, North Carolina; James McLean, Jr., Parris Island, South Carolina; Sun Oil Company, Dallas, Texas; and various branches of the Army and Navy. Further acknowledgments may be found under the respective states.

R. S. Bassler, of the United States National Museum, Washington, D. C., has identified some of the Bryozoa and Joseph A. Cushman, of the Cushman Foraminiferal Research Laboratory, Sharon, Massachusetts, a few of the Foraminifera. In addition, J. B. Reeside, Jr., and L. W. Stephenson, of the United States Geological Survey, G. D. Harris and Mrs. K. V. Palmer of the Paleontological Research Institute, Ithaca, New York, and H. A. Pilsbry and B. F. Howell, of the Academy of Natural Sciences of Philadelphia, have given advice on the identification of certain doubtful or difficult specimens.

Throughout the course of this study the writer has had the opportunity of conferring with numerous geologists who are interested in the possibility of obtaining petroleum from the East Coast. These conferences were highly fruitful, and much valuable information was obtained.

Finally, the writer acknowledges the help in the sorting and identification of

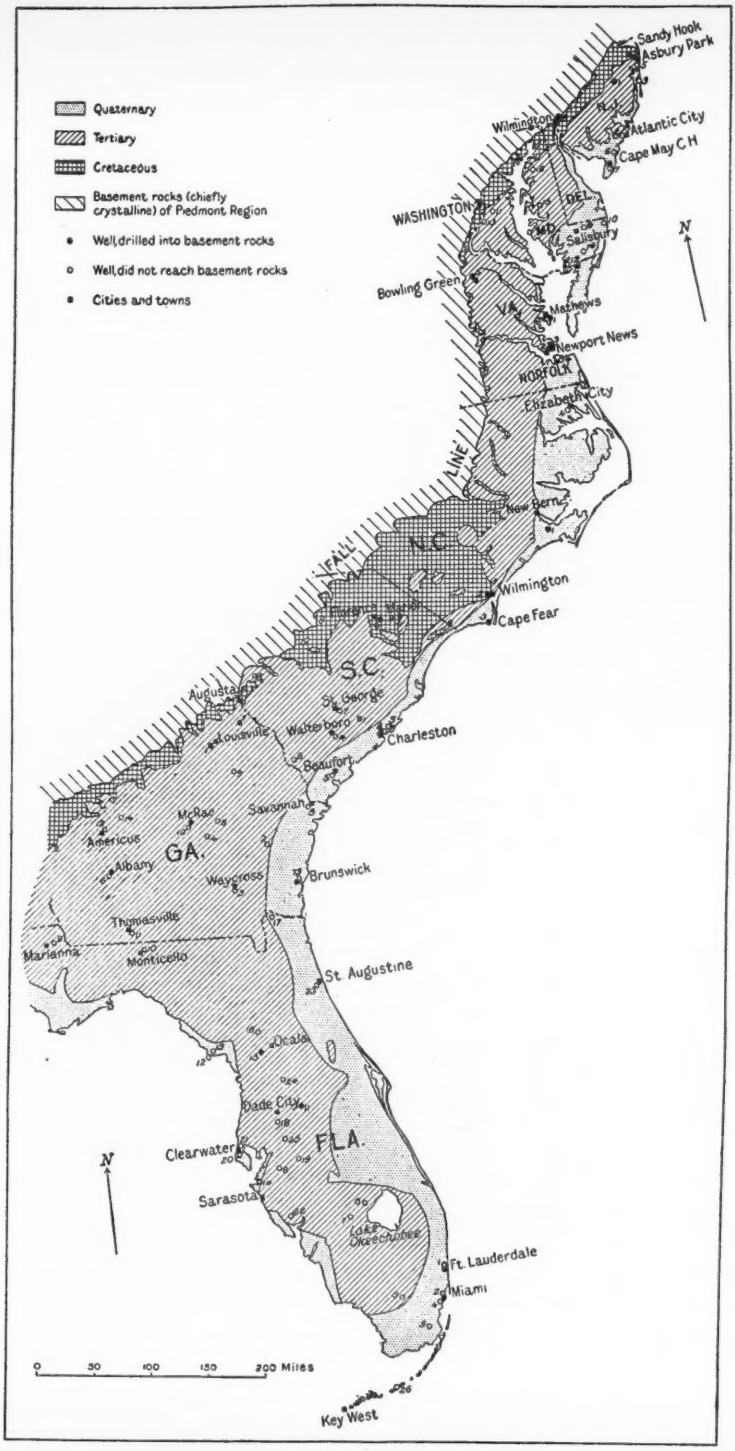

FIG. 1.—Map showing general geology of Atlantic Coastal Plain (after Postley).

TABLE I—CORRELATION TABLE OF ATLANTIC COASTAL PLAIN FORMATIONS

	New Jersey	*Delaware*	*Maryland*	*Virginia*	*North Carolina*	*South Carolina*	*Georgia*	*Florida*	*Gulf*
Pleistocene	Cape May	Cape May	Pamlico Talbot	Pamlico Talbot	Pamlico Talbot	Pamlico Talbot	Pamlico Talbot	Anastasia Miami ¡ Key Largo Fort Thompson	Beaumont
	Pensauken	Columbia gr.: Penhaloway? Wicomico?	Penhaloway Wicomico	Penhaloway Wicomico	Penhaloway Wicomico	Penhaloway Wicomico	Penhaloway Wicomico		Lissie
	Bridgeton	Sunderland Coharie Brandywine?	Sunderland Coharie Brandywine	Sunderland Coharie Brandywine	Sunderland Coharie Brandywine	Sunderland Coharie Brandywine	Sunderland Coharie Brandywine	?	Willis
Pliocene	Beacon Hill	Bryn Mawr	"Lafayette"	"Lafayette"	"Lafayette"[1] Croatan Waccamaw	"Lafayette" Waccamaw	"Lafayette"? Charlton	— Caloosahatchee	Goliad
Miocene	Cohansey	Cohansey	—	Yorktown	Duplin Yorktown	Duplin- Raysor	Duplin	Choctawatchee	Pascagoula
	Kirkwood: St. Mary's Calvert	Chesapeake gr.: St. Marys Choptank Calvert	Chesapeake gr.: St. Marys Choptank Calvert	St. Marys Choptank Calvert	— — —	Hawthorne	Hawthorne	Alum Bluff Hawthorne	Hattiesburg
	—	—	—	—	Trent	—	Tampa	Tampa	Catahoula
Oligocene	—	—	—	—	—	Flint River —	Suwannee —	Suwannee Byram	Chickasawhay Vicksburg
Eocene	*	*	*?	*	Castle Hayne	Cooper Santee	Ocala: Cooper Barnwell Twiggs cl.	Ocala	Jackson
	Shark River Manasquan	Pamunkey: Nanjemoy	Nanjemoy	Nanjemoy	[2] *	McBean	McBean	Avon Park* Tallahassee* Lake City*	Claiborne
	Rancocas: Vincentown Hornerstown	Aquia	Aquia	Aquia		Black Mingo	Wilcox	Oldsmar*	Wilcox
	Rancocas: Hornerstown (part)*	*	*	*	—	*	Clayton	Cedar Keys*	Midway
Upper Cretaceous	Monmouth: Tinton Red Bank Navesink Mt. Laurel	— — Monmouth	— — Monmouth	—	Peedee	Peedee	Providence Ripley	*	Navarro
	Matawan: Wenonah Marshalltown Englishtown Woodbury Merchantville	— Marshalltown Englishtown Crosswicks	Matawan	—	Snow Hill Black Creek	Black Creek	Cusseta Ripley	*	Taylor
	Magothy	Magothy	Magothy	—	—	*?	Eutaw	*	Eutaw Austin
	Raritan	Raritan	Raritan	*	Tuscaloosa	Tuscaloosa	Tuscaloosa	*	Tuscaloosa Woodbine
Lower Cretaceous	Potomac*	Potomac: Patapsco Arundel* Patuxent	Patapsco Arundel Patuxent	— — Patuxent	—	—	*	*	Comanche

[1] Gravels at higher elevation than Brandywine.

[2] Outcrops near Garner, Clayton, Raleigh, Lillington, N. C., and well at Williamston, N. C.

* Subsurface only.

many of the samples performed by Miss Anne Harbison and Mrs. Olive Noble, both of the Academy of Natural Sciences. The drafting is by Miss Hannah Brown.

The following symbols indicate the location of the well samples.

NJGS	New Jersey Geological Survey, Trenton, New Jersey
LW	Woolman Collection, Academy of Natural Sciences, Philadelphia, Pennsylvania
ANSP	Academy of Natural Sciences, Philadelphia, Pennsylvania
MdGS	Maryland Geological Survey, Baltimore, Maryland
VaGS	Virginia Geological Survey, Charlottesville, Virginia
NCGS	North Carolina Geological Survey, Raleigh, North Carolina
NCSM	North Carolina State Museum, Raleigh, North Carolina
USGS	United States Geological Survey, Washington, D. C.
GaGS	Georgia Geological Survey, Atlanta, Georgia
AlaGS	Alabama Geological Survey, Tuscaloosa, Alabama
FlaGS	Florida Geological Survey, Tallahassee, Florida
SUN	Sun Oil Company, Dallas, Texas

Unless otherwise indicated samples from every well have been examined by the writer. Where the record is entirely from the reports of others, an asterisk(*) precedes the notation.

No attempt has been made to give complete logs of the wells. In many cases more detailed logs are available elsewhere, to which references are given. Further detailed logs of some of the wells included in this report are on file in the department of geology and paleontology of the Academy of Natural Sciences of Philadelphia and may be consulted by those interested.

The following abbreviations are used throughout the logs.

Bry. = Bryozoa
Cl. = Clay
Diat. = Diatoms
Forams. = Foraminifera
Frag. = Fragments
Glauc. = Glauconite (glauconitic)
Gr. = Gravel
Ls. = Limestone
S. = Sand
Sh. = Shells
Ss. = Sandstone

New Jersey

Through the courtesy of Meredith E. Johnson, State geologist of New Jersey, the writer has been permitted to examine the collection of well samples in the New Jersey Geological Survey in Trenton. Selection was made of the deepest and most recent wells about which little or nothing has hitherto been published. However, in order to complete the picture a restudy was made of various older wells that were originally reported by Woolman. Numerous New Jersey well samples from the Woolman Collection at the Academy of Natural Sciences were also consulted.

The most complete information on the subsurface geology of the New Jersey Coastal Plain is included in a series of publications by Lewis Woolman which appeared in the reports of the New Jersey Geological Survey between 1890 and 1902.[3] These have been consulted freely in making correlations.

[3] For convenience it is assumed that these reports appeared during the year for which they were written. Thus, Woolman (1890) means the report for 1890.

[1] Gravels at higher elevation than Brandywine. [2] Outcrops near Garner, Clayton, Raleigh, Lillington, N. C., and well at Williamston, N. C. • Subsurface only.

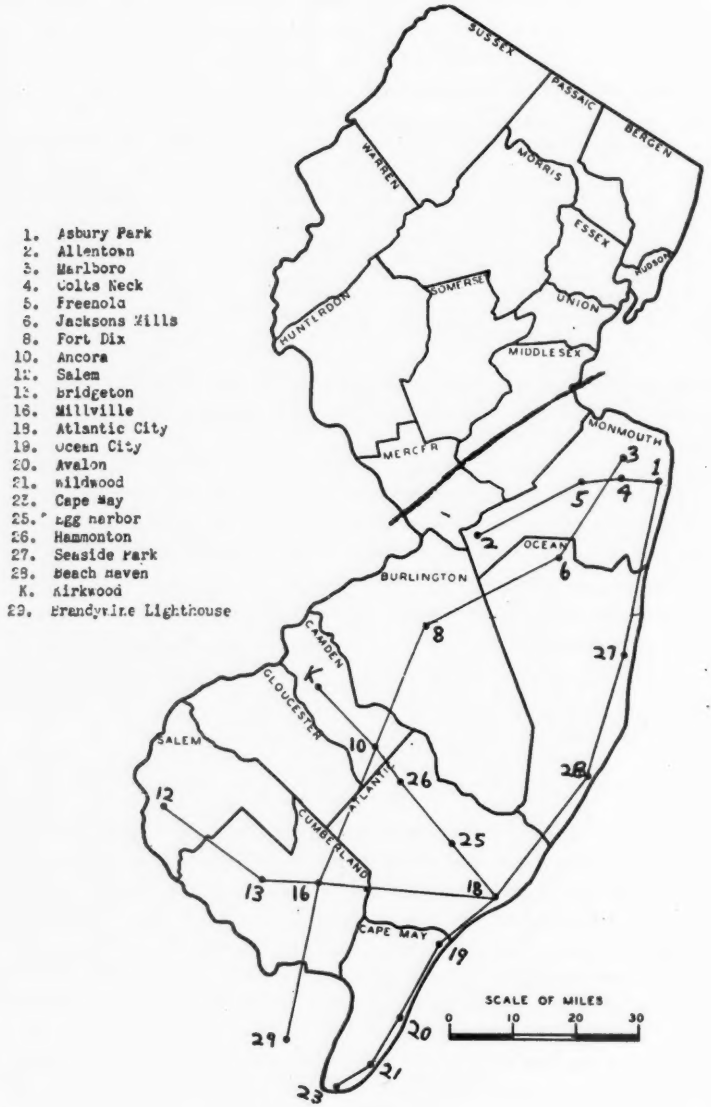

FIG. 2.—Outline map of New Jersey.

1. ASBURY PARK, MONMOUTH CO., N. J.
Keystone Laundry Elev. 18 ft. Depth 580 ft. NJGS

Depth in Feet	*Description of Sample*	*Time Division*	*Formation*
0– 55	S., cl.	Miocene	Kirkwood
–129	Greensand, cl.	Eocene	Manasquan-Shark R.
–275	Fine greensand, Bry.	"	Vincentown
–315	Greensand marl, sh.	"	Hornerstown
–385	Gray cl., glauc.	Up. Cret.	Red Bank
–425	Gray cl., Belemnite	"	Navesink
–465	Gray clayey s.	"	Mt. Laurel-Wenonah
–518	Gray cl.	"	Marshalltown
–580	Gray slightly glauc. s., sh. frag.	"	Englishtown

Only a few macrofossils were observed in these samples and the correlation is largely based on data supplied by M. E. Johnson. One specimen of *Terebratella atlantica* was found in the Hornerstown at 280 feet, and a specimen of *Belemnitella americana* from the Navesink at 400 feet. One specimen of *Spirulaea rotula* was found at the depth of 450 feet in the Mt. Laurel-Wenonah. This species is characteristic of the Vincentown and has not been found earlier than the Eocene. Since the matrix of the shell resembles that of the Vincentown rather than that of the Mt. Laurel-Wenonah, it may be assumed that the shell fell from the overlying Vincentown.

It should also be observed that shell fragments were found in the Englishtown sand, a formation from which no fossils had hitherto been recorded.

The State geologist also gave samples from this well to Steven Fox, of Princeton University, who assigned them to some of his students[4] for foraminiferal studies.

Their most significant conclusions are the following.

1. The Shark River and Manasquan formations are probably a single unit.

2. The Hornerstown microfauna is at least in part of Midway age rather than all Wilcox as previously correlated.

3. Good microfaunas are recorded from all Cretaceous formations (Englishtown to Red Bank) and suggest correlation with the lower Navarro and upper and middle Taylor of the Gulf Coast.

1a. ASBURY PARK, MONMOUTH CO., N. J. Elev. 18 ft. Depth 1,321 ft. LW

In deeper wells at Asbury Park the Raritan occurs between 950 and 1,321 feet, with the water-bearing sand between 1,000 and 1,135 feet. It is believed that the Lloyd sand, one of the main water-bearing sands of Long Island is still lower than 1,321 feet at Asbury Park (Woolman, 1895, pp. 74–75; Thompson, 1930).

[4] O'Neal on Shark River-Manasquan; Haviland on Hornerstown; Rose on Vincentown; Greene and Young on Cretaceous. Theses in library, department of geology, Princeton University.

2. ALLENTOWN, MONMOUTH CO., N. J.

F. H. Valsing well (1943) Elev. 100 ft. Depth 238 ft. NJGS

10– 35	S., cl.	Pleist.	
– 85	Gray and black cl.	Up. Cret.	Woodbury
–135	Greenish black cl., some glauc.	"	Merchantville
–175	Dark sandy cl.	"	?
–200	Black cl.	"	Magothy
–238	Slightly clayey s.	"	Raritan

No macrofossils; correlations after M. E. Johnson.

3. MARLBORO, MONMOUTH CO , N. J.

P. D. Van Mater (1943) Elev. 170 ft. Depth 246 ft. NJGS

20– 35	Cl., medium to fine s.	Up. Cret.	Red Bank
– 65	Cl., coarse to fine s.	"	Navesink
–135	Cl., medium s.	"	Mt. Laurel-Wenonah
–175	Dark gray cl.	"	Marshalltown
–246	S.	"	Englishtown

No macrofossils; correlations after M. E. Johnson.

4. COLTS NECK, MONMOUTH CO., N. J.

Fred Stout (1944) Elev. 125 ft. Depth 680 ft. NJGS

10– 25	Glauc. cl., s., ironstone	Up. Cret.	Tinton?
–125	Brown clayey s., some glauc.	"	Red Bank
–165	Glauc. cl., sh. frag.	"	Navesink
–245	Slightly glauc. s., cl., sh. frag.	"	Mt. Laurel-Wenonah
–300±	Gray micaceous slightly glauc. s., few sh. frag.	"	Marshalltown
–395	Fine clayey s.	"	Englishtown
–460±	Gray cl., some mica, sh. frag.	"	Woodbury
–560±	Sandy cl. sh. frag.	"	Merchantville
–680	Very fine s., some cl.	"	Magothy

Fossil fragments not identifiable; correlations by M. E. Johnson.

4a. COLTS NECK

United States Naval Ammunition Depot.
Raritan between 788 and 830 feet.

5. FREEHOLD, MONMOUTH CO., N. J.

Cameron Robeson Co. Elev. 140 ft. Depth 650 ft. NJSG, ANSP

0– 15	Sandy cl., glauc.	Eocene	Hornerstown
–105	Greenish yellow glauc. s.	Up. Cret.	Red Bank
–135	Gray glauc. cl., sh. frag.	"	Navesink
–195	Gray s., cl.	"	Mt. Laurel-Wenonah
–225	Dark gray micaceous cl. sh. frag., shark teeth	"	Marshalltown
–355	Gray s., cl.	"	Englishtown
–425	Gray cl., few sh. frag.	"	Woodbury
–536±	Gray sandy cl. with glauc.	"	Merchantville
–605	Sandy cl., some pyrite	"	Magothy
–650	Fine to medium slightly clayey yellow s.	"	Raritan

Fossil fragments not identifiable; correlations after M. E. Johnson.

6. JACKSON'S MILLS, OCEAN CO., N. J.

N. J. Oil and Gas Fields Co's. W. & K. Oil Co. Elev. 110 ft. Depth 5,022 ft.

0–1,336	Cret. and younger	
–5,022	Pre-Camb.	Wissahickon schist

Two oil tests were drilled in 1921 at Jackson's Mills to 3,240 and 5,022 feet, respectively. The complete logs are not available (Johnson, 1929, pp. 18–21; 1931, p. 28).

In connection with geophysical studies along a line between Plainsboro, N. J.,

and Silverton, N. J., Ewing, Woollard, and Vine (1939, p. 278) give the following incomplete data based on the oil test well at Jackson's Mills.

	Depth Below Surface (Feet)
Base of Pleistocene	—
Kirkwood	—
Manasquan	103
Vincentown	—
Hornerstown	—
Red Bank-Tinton	332
Navesink	—
Mt. Laurel-Wenonah	485
Marshalltown	—
Englishtown	—
Woodbury	692
Merchantville	754
Magothy	—
Raritan	1,336

Another oil test was drilled to about 1,100 feet near Prospertown.

7. JACKSON'S MILLS, OCEAN CO., N. J.
Clayton well; 1 m. S. town Elev. 110 ft. Depth 98 ft. NJGS

No log or complete set of samples is available. Eocene (Manasquan-Shark River) fossils occur at 50 feet. These include *Trochocyathus conoides* (Gabb & Horn), *Ostrea bryani* Gabb, *Siphonalia* n. sp. and shark teeth.

8. FORT DIX, BURLINGTON CO., N. J.
Colored Recreation Center, Hanover Lake Elev. 85 ft. Depth 485 ft. NJGS

10– 25	Yellow s.	Miocene	Cohansey
– 85	Gray clayey s., some cl.	"	Kirkwood
–145	Green cl.	Eocene	Manasquan
–215	Green cl.; glauc.	"	Vincentown
–245	Dark gr. glauc. cl.	"	Hornerstown
–305	Gray-green glauc. cl.	Up. Cret.	Red Bank-Navesink
–395	Green-gray s., glauc.	"	Mt. Laurel-Wenonah
–445	Sandy gray cl.	"	Marshalltown
–485	Fine to medium glauc. s., sh. frag.	"	Englishtown

Unidentifiable shell fragments occur at 445 and 480 feet in the Englishtown sand. Similar shell fragments were found in the Englishtown sand between 350 and 360 feet in a well at the Officers Club on Brindle Lake in Fort Dix.

8a. FORT DIX, BURLINGTON CO., N. J.
Post Stables, Cookstown Road Elev. 125 ft. Depth 1,050 ft. NJGS

This deeper well showed the top of the Raritan at 645 feet and was still in that formation when it stopped at 1,050 feet. Indeterminable mollusks were observed in the Raritan formation at 767 feet.

*9. DUNHAMS CORNERS, MIDDLESEX CO., N. J.
Middlesex Farms and Development Co's. Clark No. 1; 2 mi. S. Milltown Elev. 90 ft.
Depth 565 ft.

This oil test was drilled between June 1 and July 18, 1928. The following log was supplied by A. C. Hawkins who was retained as geologist by the company.

0– 20	S. gr.	Pleist.	Pensauken
–260	Cl. red shale frag. in lower 60 ft.	Up. Cret.	Raritan
–565	Red shale	Triassic	Stockton

10. ANCORA, CAMDEN CO., N. J.

Camden County Poor Farm Elev. 90 ft. Depth 325 ft. NJGS

0– 13	S. gr.	Pleis.	
–100	S., cl.	Miocene	Cohansey
–169	S. gr. sh. frag. (100–125)	"	Kirkwood?
–325	S. cl. sh.	"	Kirkwood

Fossils were numerous between 272 and 325 feet. The fauna is most probably Miocene although the assemblage is not typical of the Kirkwood. *Pecten madisonius* is the only characteristic Kirkwood species present. The broken specimens of *Callocardia* and *Calliostoma*, although not identifiable, suggest forms that occur in the Miocene of Maryland, Virginia, and North Carolina rather than New Jersey. The *Crassinella* is very close to *C. duplianus* Dall which is known from the Calvert (lower Kirkwood) of Maryland and also from the Miocene and Pliocene of the Carolinas. The New Jersey specimen shows a slight variation in the beak. The oyster is very questionably referred to *O. thomasii* "Conrad" Martin, which is known from the Calvert of Maryland. It is sometimes regarded as a variety of the Eocene and Oligocene *O. sellaeformis*. *Mulinia lateralis* is known from the Miocene to the Recent, but is rare in the Kirkwood.

We may conclude that the fauna between 272 and 325 feet belongs to the Miocene, probably the Kirkwood, and possibly represents an early and hitherto unrecognized phase. It is interesting to note than no Miocene fossils were found in the well at Hammonton, N. J.

11. CLEMENTON, CAMDEN CO., N. J.

Borough well Elev. 90 ft. Depth 652 ft. NJGS

0–129	S., clayey s.	Miocene and Eocene	
–141	Glauc. cl., s. sh. frag.	Up. Cret.	Navesink
–250	Fine glauc. micaceous s.	"	Mt. Laurel-Wenonah Marshalltown
–396	Glauc. s., some cl.	"	Englishtown-Woodbury
–438	Gray glauc. cl.	"	Merchantville
–600	Glauc. s., fossils, lignite	"	Magothy-Raritan
–652	Slightly glauc. s., sh. frag. and lignite	"	Raritan

12. SALEM, SALEM CO., N. J.

Test well Elev. 12 ft. Depth 1,440 ft. NJGS

0– 21	Medium coarse yellow s.	Pleis.	Cape May
– ?	Glauc. with a little quartz	Eocene	Hornerstown
– 71	Glauc. with a little quartz	Up. Cret.	Navesink
– 155	S., glauc.	"	Mt. Laurel-Wenonah
– 186	Fine clayey glauc. s.	"	Marshalltown
– 266	Gray cl.	"	Englishtown-Woodbury
– 335	Glauc. cl. and s.	"	Merchantville
– 426±	Gray cl., some s.	"	Magothy
–1,058	Pink and gray cl., some s.	"	Raritan
–1,376	Clayey s.	Low. Cret.	Potomac
–1,440	Weathered granite	Pre-Cambrian?	

It is difficult to draw the line between the Lower and Upper Cretaceous, but in view of the great thickness of the pre-Magothy, it seems logical to suppose that the Potomac group extends across the Delaware River from outcrops in Delaware. The foregoing log was supplied by M. E. Johnson, and the division between the Lower and Upper Cretaceous is after Lincoln Dryden[5] of Bryn Mawr College, who has studied the heavy minerals.

13. BRIDGETON, CUMBERLAND CO., N. J.

Test well	Elev. 95 ft.	Depth 1,651 ft.	NJGS
0– 101	Coarse yellow s.	Miocene	Cohansey
– 295	Gray cl., sh. frag.	"	Kirkwood
– 373	Greenish gray cl.	Eocene	Shark River-Manasquan
– 706	Light gray-green cl.	"	Vincentown
– 764	Cl., glauc., few sh. frag.	"	Hornerstown
		Up. Cret.	Navesink
– —	Cl. with glauc.	"	Mt. Laurel-Wenonah
–1,043	Cl.	"	Marshalltown
–1,094	Glauc. s.	"	Englishtown
–1,335	Cl. (no samples)	"	Englishtown-Woodbury
			Merchantville
–1,425	S., cl.	"	Magothy
–1,651	Fine s. cl.	"	Raritan

Correlation based on lithology, in part after M. E. Johnson.

14. PARVIN STATE PARK, SALEM CO., N. J.

7 mi. W. of Vineland	Elev. 70 ft.	Depth 129 ft.	NJGS
0– 68	S.	Miocene	Cohansey
–129	Sandy cl. with sh.	"	Kirkwood

15. SHILOH, CUMBERLAND CO., N. J.

Gorson and McCormick (1944)	Elev. 90 ft.	Depth 185 ft.	NJGS
40–120	Yellow buff s.	Miocene	Cohansey
–185	Gray chocolate cl. sh.	"	Kirkwood

16. MILLVILLE, CUMBERLAND CO., N. J.

Cumberland Oil and Gas Co.'s Steelman Farm; 2¼ mi. E. Millville Elev. 40 ft.
Depth 705 ft. NJGS?; USGS

0–212	S., cl.	Pleis. and Miocene	Cohansey
–580	S., cl., sh.	Miocene	Kirkwood
–705	Limerock, cl.	Eocene	Vincentown

This was an oil test drilled about 1916. For further discussion of the Miocene fossils from this well see Richards and Harbison (1942, pp. 175–76, 223).

Geophysical work by Ewing, Wollard, and Vine (1940, pp. 1832, Pl. 6) suggests that the basement rock (pre-Cambrian) occurs at a depth of about 3,419 feet at Millville.

17. NEWPORT, CUMBERLAND CO., N. J. Elev. 15 ft. Depth ±2,100 ft.

In 1918 an oil test was drilled 1.5 miles east of Newport by the Logan Natural Gas and Fuel Company. The company has disbanded and nothing further can be learned of the well.

[5] Personal communication to M. E. Johnson.

18. ATLANTIC CITY, ATLANTIC CO., N. J.

Youngs Pier; Tennessee Ave. Elev. 5 ft. Depth 2,306 ft. LW; NJGS

0– 90	S., cl., sh.	Pleis.	Cape May
– 126	S., gr.	"	Pensauken?
– 390	Yellow and orange s.	Miocene	Cohansey
–1,240	S., cl., diat., sh.	"	Kirkwood
–1,440	Cl., forams.	Eocene	Manasquan?
–1,900	Limesand, forams.	"	Vincentown
–2,150	Greensand	Eocene Up. Cret.	Hornerstown Navesink-Red Bank
–2,306	Dark micaceous cl.	"	Mt. Laurel-Wenonah

Miocene and later after Richards and Harbison (1942); older formations in part after Woolman (1901), 110–14).
Many other water wells have been drilled at Atlantic City and fossils are numerous. See Richards and Harbison.

19. OCEAN CITY, CAPE MAY CO., N. J. Elev 10 ft. Depth 821 ft. LW

0– 75	S., sh.	Pleis.	Cape May
–115	S.	"	Pensauken?
–278	S., some cl.	Miocene	Cohansey
–821	S., cl., sh., diat.	"	Kirkwood

See Woolman (1893, p. 399), and Richards and Harbison (1942).
For other wells along the coast between Atlantic City and Cape May see Richards and Harbison (1942) and reports by Woolman.

20. AVALON, CAPE MAY CO., N. J. Elev. 8 ft. Depth 925 ft. LW

0–100	S., sh., diat.	Pleis.	Cape May
–150	S., gr.	"	Pensauken?
–280	S., cl.	Miocene	Cohansey
–925	S., cl. sh., diat.	"	Kirkwood

For complete log and list of fossils see Woolman (1898, pp. 78–83) and Richards and Harbison (1942).

Seismic tests at Avalon were unsuccessful in recording the basement rock (Ewing, Woollard, and Vine, 1940, p. 1831). Estimates based on seismic tests elsewhere along the line from Bridgeport, N. J., to Avalon, N. J., suggest the basement at about 4,800 feet. At Woodbine, N. J., the seismic tests were more successful and the basement was estimated at 4,592 feet.

21. WILDWOOD, CAPE MAY CO., N. J. Elev. 10 ft. Depth 1,244 ft. LW

0– 132	S., cl., sh., diat.	Pleis.	Cape May
– 152	S.	"	Pensauken?
– 290	White s., some cl.	Miocene	Cohansey
– 428	Cl., s., sh.	"	Kirkwood-St. Marys
–1,244	Cl., diat., s., sh.	"	Kirkwood-Calvert

The samples between 1,104 and 1,244 feet may be Eocene, although no fossils were observed.
See Woolman (1894, pp. 159–70; 1895, pp. 86–88) and Richards and Harbison (1942).

22. RIO GRANDE, CAPE MAY CO., N. J.

Wildwood Air Base well 1, 2 mi. W. Rio Grande Elev. 22 ft. Depth 274 ft. NJGS

0– 72	S., gr.	Pleis.	Cape May non-marine
–193	S., cl., sh.	"	Cape May marine
–274	S., some cl., lignite	Miocene	Cohansey

22a. RIO GRANDE, CAPE MAY CO., N. J.

Wildwood Air Base well 2 Elev. 22 ft. Depth 280 ft. ANSP

0– 97	S., gr. some cl.	Pleis.	Cape May non-marine
–196	S., cl., sh.	"	Cape May marine
–280	S., some cl., lignite	Miocene	Cohansey

This and the previous well are of interest because of the exceptional depth of the marine Cape May, possibly indicating a former Delaware River estuary.

23. CAPE MAY, CAPE MAY CO., N. J. Elev. 10 ft. Depth 1,313 ft. LW

0– 90	S., cl., sh.	Pleis.	Cape May
– 140	S., gr.	"	Pensauken?
– 310	Light-colored s., some lignite	Miocene	Cohansey
– 385±	S., cl., sh.	"	Kirkwood-St. Marys
–1,313	Cl., s., diat., sh.	"	Kirkwood-Calvert

For complete log see Woolman (1902, pp. 84–93); also Richards and Harbison (1942).

*24. HARRISVILLE, BURLINGTON CO., N. J. Elev. 25 ft. Depth 375 ft.

0– 77	S.	Pleis.	
–375	S., sh., marl	Miocene	Kirkwood

An old water well, drilled in 1866, discussed by Woolman (1892, pp. 288–9).

25. EGG HARBOR, ATLANTIC CO., N. J. Elev. 50 ft. Depth 310 ft. LW

0– 15		Pleis.	Cape May
–120		Miocene	Cohansey
–310		"	Kirkwood
–371		"	Kirkwood—Great Diatom bed

After Woolman (1898, p. 73).

26. HAMMONTON, ATLANTIC CO., N. J. Elev. 100 ft. Depth 316 ft. LW

0–146		Miocene	Cohansey
–316		"	Kirkwood

After Woolman (1902, p. 74).

27. SEASIDE PARK, OCEAN CO., N. J. Elev. 5 ft. Depth 515 ft. LW

0– 80	S., sh.	Pleis.	Cape May
–200	S., cl., lignite	Miocene	Cohansey
–515	Glauc. s., cl.	"	Kirkwood

See Woolman (1898, pp. 101–02).

28. BEACH HAVEN, OCEAN CO., N. J. Elev. 5 ft. Depth 575 ft. LW

0–115	S. sh., diat.; gr. at base	Pleis.	Cape May
–250	S.	Miocene	Cohansey
–575	S. cl., diat.	"	Kirkwood

See Woolman (1893, pp. 395–96).

29. BRANDYWINE LIGHTHOUSE, DELAWARE BAY, N. J.
U. S. Navy Elev. 0 ft. Depth 825 ft. NJGS, ANSP

28–120	S., cl., sh.	Pleis.	Cape May
–140	S., gr.	"	Pensauken?
–210	Sandy silt	Miocene	Cohansey
–800	S., cl., diat., sh.	"	Kirkwood
–825	Cl., greensand, sh., Bry.	Eocene	Jacksonian

For full discussion see Richards and Harbison (1944) and for Miocene diatoms, Patrick (1944). This marks the first indication of Jacksonian deposits north of North Carolina. It is characterized by *Pecten delawarensis*, *Ostrea compressirostra*, *Scalaria virginia*, *Solidobalanus* sp., and the Bryozoa *Lunularia fenestrata* and *Metradolium* spp., both identified by R. S. Bassler.

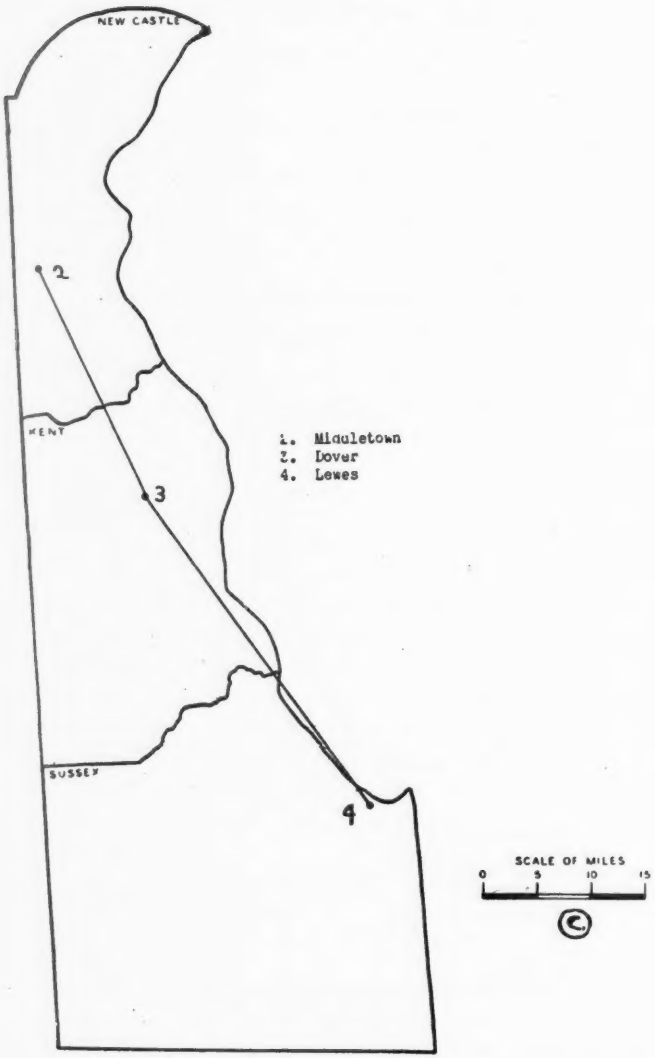

FIG. 3.—Outline map of Delaware.

OTHER OIL TESTS

Partial logs of oil tests at Millville, Jackson Mills, and Dunhams Corners were given in the previous section. The following is a list of all oil tests in the state known to the writer (largely from Johnson, 1929, p. 20).

	Year		*Depth in Feet*
1.	Before 1868	"In Ramapo Valley"	375+
2.	1915	Perron Oil and Gas Co., Cassville, Ocean Co.	600+
3.	1916	3 mi. E. Millville, Cumberland Co., Cumberland Oil and Gas Co.	705
4.	1917	Belle Meade, Somerset Co., Presumably all in Triassic	2,100
5.	1917	Hammonton, Atlantic Co.	120±
6.	1918	1.5 mi. E. Newport, Cumberland Co., East Coast Oil Co.= Logan Natural Gas and Fuel Co. of Columbus, Ohio	2,100±
7.	1919–20	In Ocean County just S. of Prospertown, N. J. Oil and Gas Fields Co.	1,100±
8.	1920–21	Jacksons Mills, Ocean Co., N. J. Oil and Gas Fields Co.	3,240
9.	1921	Jacksons Mills, Ocean Co., N. J. Oil and Gas Fields Co. and W. & K. Oil Co.	5,022
10.	1928	Dunhams Corners, Middlesex Co., Middlesex Development Co.; 2 wells	565

DELAWARE

No special collections of Delaware well material have been located. The few samples examined came largely from the Woolman Collection at the Academy of Natural Sciences, Philadelphia, or from the Sun Oil Company at Dallas, Texas. A few records of Delaware wells were given by Woolman (1890–1902) and a few logs were included in the Dover and Elkton-Wilmington folios (Miller, 1906, 1920).

*1. FORT DUPONT, NEWCASTLE CO., DEL.
Near Delaware City Elev. 10 ft. Depth 762 ft.

0– 24	S., gr.	Pleis.	Talbot=Cape May
– 60	Green s.; sh.	Eocene	Rancocas
–180	S., cl., some glauc.	Up. Cret.	Monmouth
–300	S., cl.	"	Matawan
–421	S.	"	Magothy
–762	Fine s., cl.	Up.-Low. Cret.	Raritan, Patapsco, Patuxent

Log after B. L. Miller in Elkton-Wilmington Folio (1920). See also Fuller and Sanford (1906, pp. 194–95) and Woolman (1900, pp. 132–34).

2. MIDDLETOWN, NEWCASTLE CO., DEL. Elev. 65 ft. Depth 1,478 ft. LW

0– 27	S., gr.	Pleis.	
– 45	Iron-stained s.	Eocene	Rancocas
– 110	S., greensand	"	Rancocas
– 204	S., cl.	Up. Cret.	Monmouth
– 300	S.	"	Matawan
– 425	White cl. and lignite	"	Magothy
– 686	White s., white and red cl.	"	Raritan
– 900	S., cl.	Low. Cret.	Patapsco
–1,150	Cl.	"	Arundel
–1,478	S., cl.	"	Patuxent

Log after B. L. Miller in Dover Folio (1906). See also Woolman (1901, pp. 107–09).

3. DOVER, KENT CO., DEL. Elev. 34 ft. Depth 200 ft. LW, ANSP

0– 11	S., gr. cl.	Pleis.	Cape May
–200	S., cl., sh.	Miocene	Kirkwood=Calvert

Good shells from 200 feet (water-bearing sand), including *Crassatellites galvestonensis.*

4. LEWES, SUSSEX CO., DEL. Elev. 10 ft. Depth 1,080 ft. LW

0– 125	S., gr. cl., sh.	Pleis.	Cape May
– 294	S., cl., some lignite	Miocene	Cohansey
– 404	S., sh.	"	St. Marys
– 772	Diat. cl.	"	Kirkwood
– 891	Cl.	"	Kirkwood
– 950	S.	"	Kirkwood
– 990	Diat. cl.	"	Kirkwood
–1,080	Glauc. s., marl	"	Kirkwood

The upper part of the section assigned to the Cohansey may include some early Pleistocene (Pensauken?), while the material below 268 feet is definitely Cohansey. For subdivisions of the Kirkwood of this well see Woolman (1898, pp. 83–90) and Richards and Harbison (1942). The well stopped in the "second diatom bed" near the base of the Calvert phase of the Kirkwood.

Of special interest is a well preserved shell of *Olivella mutica* at 985 feet, the first record of this species from the Chesapeake group.

5. BRIDGEVILLE, SUSSEX CO., DEL.
Russell Farm, 4 mi. SE. Bridgeville Elev. 45± ft. Depth 3,010 ft. SUN

Three closely spaced oil tests were drilled about 1935. The following abbreviated and generalized log is based on a study of the samples from D-5 and D-6 and on some information on the Foraminifera supplied by Kenneth A. Payne and R. L. Collins.

0– 180	No samples		
– 200	Fine sand	Miocene	Cohansey
– 700	Greenish gray s., cl., sh.	"	Kirkwood
– 850	Green and white s. sh. frag. *Solidobalanus;* forams. including *Buliminella jacksonensis*	Eocene	Jackson
–1,120	Fine- to coarse-grained s., forams. including *Ceratobulimina, Textularia, Anomalina*	"	Pamunkey
–1,330	Greensand, sh. frag. and Midway forams. including *Vaginulina longiforma, Robulus, Nodosaria, Hemicristellaria*	"	Midway
–1,650	S., cl., sh. frag., forams. including *Dorothia bullata, Anomalina taylorensis, Bolivina decorata, Cibicides*	Up. Cret.	Monmouth-Matawan
–3,000	S., cl., siderite; few forams. and ostracods including *Kyphopxa, Fondicularia* cf. *goldfussi, F. archaciana, F. gracilis* (2,051–91 ft.)	"	Raritan-Tuscaloosa

The log is especially notable for the thick section of Eocene and for the marine fossils in the Raritan-Tuscaloosa. Some of the lower part of this section may represent the Lower Cretaceous (Potomac group).

MARYLAND

The material available for study has come from the Woolman Collection at the Academy and some samples provided by N. Shannahan, of St. Michaels, Maryland. Some information was obtained from Robert R. Bennett of the

United States Geological Survey in Baltimore, but no samples were available at this source.

The most complete discussion of the subsurface geology of the Maryland Coastal Plain is included in a volume by Clark *et al.* (1918).

1. QUEENSTOWN, QUEEN ANNE CO., MD. Elev. 10 ft. Depth 260 ft. ANSP

200–270	S. gr., sh. Bry.	Eocene	Aquia?

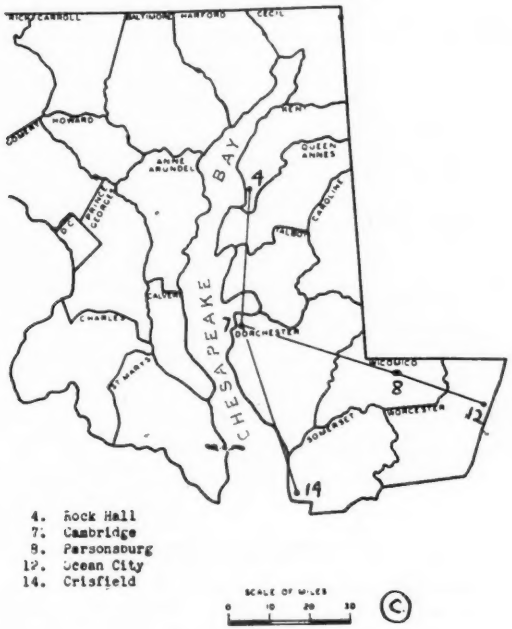

FIG. 4.—Outline map of part of Maryland.

2. DENTON, CAROLINE CO., MD. Elev. 40 ft. Depth 391 ft. ANSP

360–391	S., gr. sh. (*O. sculpturata*)	Eocene

*3. CHESTERTOWN, KENT CO., MD.
Water Works; Shannahan (1908) Elev. 22 ft. Depth 1,135 ft.

0– 60	Cl. and marl; sh.	Pleis.	
– 129	Gray and black marl; sh.	Eocene	Aquia
– 200	Green and black marl and some s.	Up. Cret.	Monmouth
– 268	S. and a little cl.	"	Matawan
– 344	Cl. and s.	"	Magothy
– 581	Cl. and fine s.	"	Raritan
– 955	Cl. and a little s.	Low. Cret.	Patapsco
–1,135	Cl.	"	Patuxent

After Clark, Mathews, and Berry (1918, pp. 270–71).

4. Rock Hall, Kent Co., Md.
Artesian wells 2 and 3 Elev. 15 ft. Depth 345 ft. LW

0– 21		Pleis.	
–132		"	Cape May
–180?		Eocene	Rancocas
–220		Up. Cret.	Monmouth
–297		"	Matawan
–345		"	Raritan

Log modified after Woolman (1898, pp. 116–21).

5. St. Michaels, Talbot Co., Md. Elev. 8 ft. Depth 400 ft. ANSP
Single samples from several wells in this vicinity received from Norman Shannahan. They are from water-bearing sand, presumably Eocene (Nanjemoy). A few fossils identified:

St. Michaels	370	*Ostrea sculpturata;* Bryozoa
3 mi. N. St. Michaels	321–31	*O. compressirostra*
McDaniel well	340–80	Fragments

*6. Easton, Talbot Co., Md. Elev. 30 ft. Depth 1,015 ft.
Several wells near Easton including deep one at Water Works (1,015 ft.) discussed by Clark *et al.* (1918, pp. 295–97). No samples available; impossible to recognize formations from logs.

7. Cambridge, Dorchester Co., Md. Elev. 20 ft. Depth 540 ft. ANSP, LW

75–350±	Cl., s. sh. frag.	Miocene	Chesapeake
–540	Greensand	Eocene	Nanjemoy

Based on Woolman's samples to 350 feet and a single sample from 540 feet supplied by Shannahan.

*8. Parsonsburg, Wicomico Co., Md.
St. Martins Oil and Gas Co. Elev. 80 ft. Depth 1,186 ft.
An oil test drilled in 1918. According to Clark *et al.* (1918, pp. 315–19), entire section probably Miocene. No samples available.

9. Salisbury, Wicomico Co., Md.
Ice House Elev. 15 ft. Depth 424 ft. LW

0–100±		Pleis.	
–424		Miocene	Cohansey and Chesapeake

See Woolman (1899, pp. 112–15) and Clark *et al.* (1918, p. 314).

10. Sharptown, Wicomico Co., Md. Elev. 15 ft. Depth 300 ft. ANSP

260–300	Ls., sh. frag.	Miocene	Choptank

11. Pocomoke City, Worcester Co., Md. Elev. 8 ft. Depth 496 ft. LW

0– 15	Made ground	Recent	
– 30	Yellow and brown cl.	Pleis.	
–496	Cl., s., sh.	Miocene	Chesapeake
496	Coarse water-bearing s.	"	Chesapeake

After Woolman (1899, pp. 116–17). A deeper well (1,400 ft.) obtained water from Eocene (Aquia) but no samples available.

12. Ocean City, Worcester Co., Md. Elev. 5 ft. Depth 270 ft. LW

0– ?	S.	Pleis.	
–270	S.	Miocene	Chesapeake

*13. Isle of Wight, Worcester Co., Md.
Isle of Wight Oil Co. (1914) Elev. 6 ft. Depth 1,706 ft.

According to Clark *et al.* (1918, p. 327) the well was still in the Miocene (Calvert) when it was abandoned at 1,706 feet. A "mineral water" was encountered

at 1,700 feet which was "quite different from the normal type of Calvert waters found further northwest and nearer to the surface and to the catchment area for these waters." It is possible that this is Eocene or older.

14. CRISFIELD, SOMERSET CO., MD. Elev. 5 ft. Depth 1,060 ft. LW

0– 52	Cl. and s.	Pleis	
– 240	S., cl. and sh.	Miocene	St. Marys
– 771	S., cl., and sh.	"	Calvert
– 900	Cl., forams.	Eocene	
–1,060	S. cl.	Up. Cret. or Eocene	

15. PATUXENT RIVER, ST. MARY'S CO., MD. Elev. 106 ft. Depth 585 ft. ANSP
U. S. Naval Air Station

0–318	Cl., sh. frag.	Miocene	Calvert
–585	Greensand, sandy cl., sh. frag.	Eocene	Pamunkey

At Solomons, opposite Air Station, water supply probably comes from Eocene at depth of about 250 feet (R. R. Bennett).

*16. MEADOWS, PRINCE GEORGE CO., MD.
Oil Prospecting well, 1 mi. S. Meadows Elev. 268 ft. Depth 1,522 ft.
For log see Clark *et al.* (1918, pp. 383–84). Well did not reach base of Patuxent.

*17. FORT WASHINGTON, PRINCE GEORGE'S CO., MD. Elev. 120 ft. Depth 1,000 ft.

Clark *et al.* (1918, pp. 386–87) give the partial log of a well that was drilled to a depth of 1,000 feet without reaching crystalline rock. They observe that the well "shows an extraordinary thickness for Lower Cretaceous deposits at a point near where they have been thought to thin out. An obvious and probably the correct explanation is that the well is located along an old stream channel, that of the pre-Cretaceous Potomac."

18. SALISBURY, WICCOMICO CO., MD.
Ohio Oil Co's. L. G. Hammond No. 1; 6 mi. E. Salisbury Elev. 57 ft.
Depth 5,563 ft. ANSP, MdGS

This is the first important oil test along the Atlantic Coastal Plain north of Georgia, and was drilled between November, 1944, and January, 1945. The following is a preliminary correlation prepared by the writer after examining the cores and is published with the permission of the Ohio Oil Company. A slightly more extended report is now being prepared by the present writer and will be submitted to the *Bulletin* in the near future.

0– 100	S., gr.	Pleis.	Wicomico
– 320	S., gr. lignite	Miocene	Cohansey
– 540	S., sh.	"	St. Marys
– 620	S., ss., ls., sh.	"	Choptank
–1,160	Silt, cl., sh. diat.	"	Calvert
–1,200±	Glauc. cl., forams.	Eocene	Jackson
–1,380	Glauc., s., cl. sh. frag.	"	Pamunkey (and Midway?)
–1,807	S., cl., forams. (shells 1568–1618)	Up. Cret.	Monmouth-Matawan
–2,300±	S., cl., lignite (shells 2240–2277)	"	Magothy-Raritan
–5,360	Alternating s., and cl. with lignite, becoming consolidated near base	Low Cret.	Potomac
–5,529	Red and green sh.; ss.	Triassic	Newark
–5,563	Granite, pegmatite	Basement Complex	Pre-Cambrian?

VIRGINIA

The Virginia Geological Survey, working in coöperation with the Ground-Water Division of the United States Geological Survey, has obtained a collection of well samples from the Coastal Plain of Virginia. Through the kindness of Arthur Bevan, State geologist, and D. J. Cederstrom, of the United States Geological Survey, the writer was permitted to examine many of these samples. He is also indebted to Cederstrom for spending several days in the field with him in Virginia and in discussing various problems related to this work.

FIG. 5.—Outline map of part of Virginia.

Three papers by Cederstrom (1945 a, b, c) summarize the present knowledge of the subsurface geology of southeastern Virginia.

Several wells in the Norfolk area were discussed by Woolman, and the samples are in the Woolman Collection at the Academy.

1. OLD POINT COMFORT, ELIZABETH CITY CO., VA.
Chamberlin Hotel Elev. 10 ft. Depth 945 ft. LW

0– 10	Fine s. and gr.	Pleis.	
–610	S., cl., and shells (shells mostly above 300 ft.)	Miocene	Chesapeake
–800	S. and cl.	Eocene	
–945	S.	"	

Woolman correlated the deepest layer with the Cretaceous because of the presence of *Terebratula harlani*, but this species is characteristic of the Eocene as more recently defined. See Woolman (1898, pp. 122–26).

2. FORT MONROE, ELIZABETH CITY CO., VA. Elev. 10 ft. Depth 865 ft. LW

0–600±	S. cl. and sh.	Miocene	Chesapeake
–865	Cl.	Eocene	

*3. FORT MONROE, ELIZABETH CITY CO., VA.
New Government well (1902) Elev. 10 ft. Depth 2,254 ft. VaGS

0– 50		Pleis.	
– 610		Miocene	Chesapeake; Calvert at base
–1,440		Eocene	
–2,246		Low. Cret.	Potomac
–2,254		Pre-Camb.	

A restudy of these samples by Cederstrom (1945a) has revealed a considerable thickness of Eocene (620 feet), as contrasted with Norfolk on the opposite side of James River (90 feet). Calvert Foraminifera were recognized in the 600-foot sample.

3a. NEWPORT NEWS, WARRICK CO., VA.
Gas Works Elev. 12 ft. Depth 1,082 ft.

0– 34	Sandy cl.	Pleis.	Columbia
– 403	S., cl., shell marl	Miocene	Chesapeake
– 720	Glauc. cl.	Eocene	Nanjemoy
–1,082	S., cl., some glauc.	"	Aquia

Of special interest because of exceptionally thick Eocene (Cederstrom, 1945a).

4. NORFOLK, NORFOLK CO., VA.
Moores Bridge; 5 mi. E. Norfolk Elev. 12 ft. Depth 1,740 ft. LW, VaGS

0– 65	S. sh. frag.	Pleis.	Pamlico
– 625	Cl. sh. frag.	Miocene	Chesapeake
– 685	Cl., forams.	Eocene	Jackson?
– 715	Cl.	"	Pamunkey
– 783	S. sh. (*Exogyra* n. sp.)	Up. Cret.	Raritan-Tuscaloosa
–1,320	S.	Low. Cret.	Potomac
–1,740	S., some cl.	"	Potomac

In part after Woolman (1899, pp. 92–102). Jackson (?) Foraminifera identified by Cushman (see Cederstrom, 1945a, b). The Upper Cretaceous is characterized by the presence between 755 and 780 feet of *Exogyra* n. sp. closely related to *E. columella* from the Eagle Ford formation of Texas. Darton (1896, p. 415) records an *Exogyra* at 1,320 feet, but it is probable that this fell, from a higher depth.

5. NORFOLK, NORFOLK CO., VA.
Lamberts Point, 2 mi. NW. Norfolk on N. & W. RR. Elev. 10 ft. Depth 616 ft. LW

0–526	Miocene	
–616	Up. Cret. or Eocene	

Modified from Woolman (1899, p. 87).

6. LAKE PRINCE, NANSEMOND CO., VA.
City of Norfolk Water Co. Elev. 67 ft. Depth 970 ft. VaGS

0– 26	Yellow s.	Pleis.	Columbia
–295	Blue shell marl	Miocene	Chesapeake
–323	S., glauc.	Eocene	Pamunkey
–372	Gray cl., glauc.	"	Pamunkey
–427	Gray cl., some glauc.	Up. Cret.	Tuscaloosa
–970	S., cl., no fossils	Low. Cret.	Potomac

One sample labelled 460–920 feet contained a mixture of Miocene species, *Gryphaeostrea vomer* and *Spirulaea rotula* (Eocene) and *Exogyra* n. sp. (Cretaceous). For further data see Cederstrom (1945c).

7. DRIVERS, NANSEMOND CO., VA.
Monogram Farm Elev. 20 ft. Depth 540 ft. VaGS

0– 45	S., gr., cl.	Pleis.	Columbia
–315	Blue cl., marl	Miocene	Chesapeake
–354	Green sandy marl	Eocene	Pamunkey
–373	Green cl., forams.	"	Pamunkey or Midway
–509	Gray cl., s., *Exogyra* n. sp., forams.	Up. Cret.	Tuscaloosa
–540	Clayey s.	Low. Cret.	Potomac

For further details see Cederstrom (1945b, c).

8. PORTSMOUTH, NORFOLK CO., VA.
Norfolk Navy Yard Elev. 15 ft. Depth 89+ ft. VaGS

0–89	Cl. and sh.	Miocene	Chesapeake

9. YORKTOWN, YORK CO., VA.
Naval Mine Depot Elev 80 ft. Depth 620 ft. VaGS

0– 50	Yellow s. and cl.	Pleis.	
–380	Blue mud; sh.	Miocene	Chesapeake
–450	Blue mud, slightly glauc.	Eocene	Pamunkey?
–620	Blue mud, slightly glauc.	"	Midway?

See Cederstrom (1945a).

10. FORT EUSTIS, WARRICK CO., VA. Elev. 35 ft. Max depth 692 ft. VaGS

Generalized Log

0– 30		Pleis.	
–300		Miocene	Chesapeake
–692		Eocene	Pamunkey and Midway?

Macrofossils obtained only from Miocene section. Additional log after Cederstrom (1945c).

11. CAMP PEARY, YORK CO., VA.
Seabee Base Elev. 80 ft. Max. depth 479 ft. VaGS
Samples examined from eight wells. Following log (B-5) is typical.

0– 24	Silty s.	Pleis.	Columbia
–315	Blue and green cl. and sh.	Miocene	Chesapeake
–436	Glauc. s., some cl.	Eocene	Pamunkey
–473	S., some cl.	"	

See Cederstrom (1945a).

12. BACONS CASTLE, SURRY CO., VA.
Water Supply, City of Newport News Elev. 75 ft. Depth 1,060 ft. VaGS

Well No. 1

0– 26	Yellow silty s.		Pleis.	Columbia
– 306	Cl. and sh., marl		Miocene	Chesapeake
– 325	Glauc. s. and cl.		Eocene	Pamunkey
– 409	Tough gray cl.	(*Terebratula harlani*)	"	Pamunkey
–1,060	S., cl.		Low. Cret.	Potomac

12a. BACONS CASTLE, SURRY CO., VA.
Water Supply, City of Newport News Elev. 97 ft. Depth 799 ft. VaGS

Well No. 2

0– 30	S., cl.	Pleis.	Columbia
–287	Cl., sh., marl.	Miocene	Chesapeake
–333	Glauc. s. and marl.	Eocene	Pamunkey
–388	Blue cl., some glauc.	Eocene or Up. Cret.	
–799	S., cl.	Low. Cret.	

See Cederstrom (1945b).

13. FRANKLIN, SOUTHAMPTON CO., VA. Elev. 20 ft. Max. depth 800 ft. VaGS
Considerable variation in formational thickness in this area. Log of well No. 207 at Water Works follows (partly from Cederstrom, 1945a,b).

0– 20	S.	Pleis.	Columbia
– 75	Blue cl. marl., sh.	Miocene	Chesapeake
–129	Black s. and rock	Eocene	Pamunkey
–139	Gray s.	Up. Cret.?	Tuscaloosa?
–224	Chocolate cl.	"	Tuscaloosa?
–340+	S., cl.	Low. Cret.	Potomac

13a. AIRPORT, 1 mi. E. Franklin Elev. 30 ft.

0– 19	S., some cl.	Pleis.	
–105	Blue cl. and marl.	Miocene	Chesapeake
–123	Glauc. s. and green cl.	Eocene	Pamunkey
–153	Glauc. s.	"	Midway?
–180	Gray s., brown cl.	Up. Cret.	Tuscaloosa

This is one of the few indications of any Midway deposits north of Georgia. It is suggested by the presence of *Spirulaea mcglameri*, *Pecten* n. sp. and some Foraminifera (Cushman). The Upper Cretaceous is indicated by *Exogyra* n. sp. and *Gryphaea* sp.

14. RICHMOND, HENRICO CO., VA. Elev. 150± ft. Depth 105 ft. LW

0–105	Cl. and some s.	Miocene	Chesapeake

Fossil *Pecten* and shark teeth "immediately under the diatomaceous earth."

15. SURRY COURT HOUSE, SURRY CO., VA. Elev. 125 ft. Depth 403 ft. VaGS, ANSP
Numerous species of Miocene fossils identified from dump.

16. DISPUTANTA, PRINCE GEORGE CO., VA.
School for Colored Elev. 114 ft. Depth 219 ft. VaGS

0– 25	Red and yellow cl.	Pleis.	Columbia
– 85	Blue shell marl	Miocene	Chesapeake
–135	Glauc. marl	Eocene	Pamunkey
–219	S., cl.	Low. Cret.	Potomac

Cederstrom (1945b).

17. RIEDS FERRY, NANSEMOND CO., VA. Elev. 10 ft. Depth 440 ft. VaGS

400–440	Mostly glauc.; forams., sh. frag.	Up. Cret.	

Upper Cretaceous Foraminifera identified by Cushman (Cederstrom, 1945c).

18. MATTHEWS, MATTHEWS CO., VA.
Elkins-Phillips oil test Elev. 15 ft. Depth 2,325 ft. VaGS, ANSP

Log is based on set of very small samples and partly on driller's record.

Depth in Feet				
101–	101	S. and shells; very hard "thought to be source of gas"	Miocene	Yorktown
490–	500	Dark gray fossiliferous marl, some glauconite	Eocene	Pamunkey
865–	878	Hard gray limy siltstone grading downward to greensand	"	
895–	902	Sandy green marl	"	
1,050–	58	Gray sand and shell; very hard	"	
1,110–	22	Indurated gray dark glauconitic limestone	"	
1,160–	64	Gray micaceous sand	Top, Up. Cret.(?)	
1,335–	42	Red and yellow conglomerate at base (soft water); hard gray sand at top		
1,400–	10	Fine sand and clay		
1,555–	70	Yellow clayey sand		

Depth in Feet	
1,680–1,705	Coarse sand and pebbles
1,720–1,805	Yellow clayey sand
1,805– 70	Hard red and gray clay
1,870– 76	Fine sand and clay
2,066– 70	Very hard gray sand, few pebbles
2,110– 16	Light gray micaceous sand; 2-inch pebble
2,236– 40	Sand, shale and gravel
2,265– 68	Sand and gravel; conglomerate, broken rock; arkosic material
2,307– 13	Sand, grading downward to red-yellow arkose
2,313– 18	Broken rock, arkosic; "just above granite"
2,318– 20	Basal conglomerate; arkosic
2,320– 25	Granite

Impossible to separate Upper and Lower Cretaceous on basis of incomplete samples. Cretaceous-basement contact thought to occur at 2,307 feet.

19. NEW POINT COMFORT, MATTHEWS CO., VA. Elev. 10 ft. Depth 153 ft. VaGS, ANSP

0–10	Yellow sand	Pleis.	Columbia
–153	S. and sh., marl; many fossils	Miocene	Chesapeake

20. FORT CUSTIS, KIPTOPEKE, NORTHAMPTON CO., VA. Elev. 20 ft. Depth 63 ft. VaGS

0–63	S.	Pleis. and Recent

21. CAPE CHARLES, NORTHAMPTON CO., VA.
Pennsylvania RR. Elev. 20 ft. Depth 1,810 ft.

A deep water well was drilled for the New York, Philadelphia, and Norfolk Railroad (Pennsylvania RR.). Unfortunately no samples have been located. The following is based on the driller's log.

Depth in Feet	
0– 6	Yellow sandy clay
– 40	Yellow water-bearing sand
– 46	Sandy clay
– 100	Greenish marl; shells and sand
– 145	Dark gray sand and shells
– 162	Blue clay
– 175	Green marl
– 187	Gray sand and shells
– 189	Gray clay
– 204	Sand with water (5 gals. per minute)
– 222	Very find sand
– 238	Soft green clay; shells
– 239	Shell rock
– 278	Gray sand with water (5 gals. per minute)
– 281	Dark gray clay
– 310	Dark gray sand
– 380	Lead-colored clay with a few boulders
– 475	Light green sticky clay
– 495	Soft dark green clay; a little fine sand
– 890	Tough dark green clay (boulder at 502 feet)
– 950	Green clay with black specks; soft and hard
–1,100	Light green clay; soft and hard (boulder at 980 feet)
–1,132	Light green clay; soft
–1,133	Gray clay
–1,148	Soft gray clay
–1,165	Hard and soft gray clay
–1,230	Hard greenish sand

Depth in Feet	
−1,267	Hard gray sand rock
−1,250	Hard gray sand and gravel
−1,270	Mixed brown and gray sand and clay
−1,319	Hard greenish sand
−1,331	Sand, gravel and clay; mixed; hard and soft
−1,585	Clay, gravel and sand of many colors; hard and soft places in it.
−1,607	Hard greenish sandy clay
−1,680	Pale pink sandy clay
−1,740	Lead colored clay with crusts of sandstone
−1,810	Reddish brown clay; free from sand

The following correlation is very tentative since no samples have been examined.

0– 46	Pleis.	Pamlico
– 890	Miocene	Chesapeake
−1,331(?)	Eocene	
−1,810	Cret.	

*22. BOWLING GREEN, CAROLINE COUNTY, VA. Elev. 215 ft. Depth 1,550 ft.

0– 209	No samples	Pleis., Mio., and Eocene	
– 533	S., cl.	Low Cret.	Potomac
−1,160	Ss., cl.	Triassic	
−1,550	Granite, ss.	Pre-Cambrian	

After Cederstrom (1945b, p. 30).

NORTH CAROLINA

The collection of well samples in Raleigh, obtained by the North Carolina Geological Survey in coöperation with the Ground-Water Division of the United

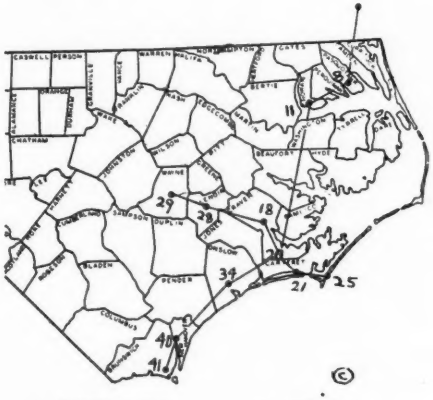

FIG. 6.—Outline map of part of North Carolina

States Geological Survey, has been consulted through the permission of J. L. Stuckey, State geologist, and M. J. Mundorff, of the United States Geological Survey. The writer is indebted to Mr. Mundorff for spending several days in the field and for criticizing this section of the manuscript. Samples from the Wilmington well were made available through Harry T. Davis, of the North Carolina State Museum in Raleigh.

A mimeographed report has recently been prepared by Mundorff (1944) which gives more detailed logs of many of the wells discussed in this report.

*1. Roduco, Gates Co., N. C. Elev. 38 ft. Depth 200 ft.

According to data received from D. J. Cederstrom, a well at Roduco, N. C., passed through a black sand with fossils between the depths of 150 and 200 feet. According to Cederstrom, this is probably Eocene. If this interpretation is correct it is one of the few records of Eocene deposits in the northeastern part of North Carolina. See also Water Lily (Log No. 6) and Williamston (Log No. 12). The Pamunkey Eocene apparently pinches out in southern Virginia toward the North Carolina line. However, some Wilcox or Claiborne fossils have been found at the western edge of the Coastal Plain near Raleigh (Richards, 1945).

2. Seabord, Northampton Co., N. C. Elev. 130 ft. Depth 154 ft. NCGS

0– 26	?	Pleis.	
– 60	Cl.	Miocene	Yorktown
–154	S., some mica	Up. Cret.	Tuscaloosa?

No fossils.

3. Roxobel, Bertie Co., N. C.
Seaboard Air Line RR. Station Elev. 97 ft. Depth 45 ft. NCGS

0–20	Pink and white cl.	Up. Cret.	Tuscaloosa
–45	Medium-coarse s.	"	Tuscaloosa

No fossils.

4. Lewiston, Bertie Co., N. C.
Griffin well Elev. 70 ft. Depth 169 ft. NCGS

2– 40	Red-brown s.	Pleis.	
– 90	S., cl.; sh. frag.	Miocene	Yorktown
–136	Medium arkosic s.	Up. Cret.	Tuscaloosa
–145	Red cl.	"	Tuscaloosa
–169	White medium s.	"	Tuscaloosa

No fossils below Miocene; for full log see Mundorff (1944).

*5. Colerain, Bertie Co., N. C.
Carolina Drilling and Equipment Co. Elev. 50 ft. Depth 273 ft.

0– 35	S. and cl.	Pleis.	
–246	Cl.; some s. and sh.	Miocene	Yorktown
–273	Black and green cl.	Eocene(?)	

No samples. Data from Mundorff (1944).

*6. Water Lily, Currituck Co., N. C.
East Coast Drilling Co.; 3.5 mi. NE. Coinjock Elev. 10± ft. Max. depth 835 ft.

Three wells were drilled as oil tests in 1921 to depths of 764, 835, and 377 feet, respectively. As far as can be learned, no samples were saved although ques-

tionable drillers' logs are available. The Miocene-Eocene contact is at about −600 feet.

7. ELIZABETH CITY, PASQUOTANK CO., N. C.
Naval Air Base; three wells Elev. 10 ft. Max. depth 70 ft. NCGS

0–70	S., cl., sh.	Pleis.	Pamlico

*8. ELIZABETH CITY, PASQUOTANK CO., N. C.
U.S.G.S. test wells Elev. 10 ft. Max. depth 482 ft.
Generalized section based on study of Foraminifera, diatoms, and mollusks by Henbest, Lohman, and Mansfield (1939). See also Lohman (1936).

0– 30	S., silt, sh., diat.	Pleis.	Pamlico
– 70	S., cl., sh., diat.	Pliocene	Croatan
–330	S., sh., cl., diat.	Miocene	Upper=Yorktown
–482	Cl. and s., no fossils	"	(?)

*8a. ELIZABETH CITY, PASQUOTANK CO., N. C. Elev. 10 ft. Depth 1,200 ft.
An older well drilled by Sydnor Pump and Well Company of Richmond, Va., in 1925, reached 1,200 feet. No samples available.

9. HARVEY NECK, PERQUIMMANS CO., N. C. Elev. 5 ft. Depth 270 ft. NCGS

0– 43	S., cl.	Pleis.	Pamlico
– 82	S., some cl., sh.	Pliocene	Croatan
–270	No samples	—	

Pliocene fauna includes *Corbula inaequalis* new var.

10. HERTFORD, PERQUIMMANS CO., N. C. Elev. 10 ft. Depth 100 ft. NCGS; ANSP

100	S., sh.	Miocene	Yorktown

Another well drilled by Sydnor in 1916 reached 713 feet; no samples or log available.

11. EDENTON, CHOWAN CO., N. C.
Marine Air Base; wells 1, 3, 4, 5, 6, 7, 9 Elev. 15 ft. Max. depth 420 ft. NCGS
Generalized Log

0– 50	S., cl., sh.	Pliocene	Croatan
–420	Cl., s., sh.	Miocene	Yorktown

The Miocene was particularly fossiliferous and included some rare species such as *Lithophaga ionensis*, *Cypraeolina dacria*, *Calliostoma humilis*, and *Mitrella* n. sp.

A sample from a well at Congers Ice Plant in Edenton yielded a good Miocene fauna at 50 feet.

12. WILLIAMSTON, MARTIN CO., N. C. Elev. 60 ft. Depth 500 ft. NCGS

0–100	S., cl., sh.	Miocene	Yorktown
–110	Greensand, sh.	Eocene	Pamunkey
–400	S., cl., sh. frag.	?	
–500	Medium coarse s.	Up. Cret.	Tuscaloosa

The presence of *Gryphaeostrea vomer* between 100 and 110 feet suggests the presence of the Pamunkey (Wilcox) Eocene. This is one of the few indications of this formation in North Carolina.

12a. Two samples from the J. R. Everett well in Williamston are as follows.

100	S., cl., sh. frag.	Miocene	Yorktown
175–200	Fine white s.; some mica	Up. Cret.	Tuscaloosa

*13. TARBORO, EDGECOMBE CO., N. C. Elev. 50 ft. Depth 349 ft.

0– 15	White s.	Pleis.	
– 65	S., cl.	Miocene	Yorktown?
–328	Cl., some s.	Up. Cret.	Tuscaloosa?
–349	Decomposed rock	Pre-Camb.?	

After Clark, Miller *et al.* (1912, pp. 104–05) and Mundorff (1944).

*14. WILSON, WILSON CO., N. C.

Dr. A. B. Williams, 9 mi. E. Wilson Elev. 123 ft. Depth 335 ft.

0– 60	Blue cl. and sh.	Miocene	Yorktown
–245	S. and cl.	Up. Cret.	Tuscaloosa
–335	Rocks	Pre-Camb.	

No samples; after Mundorff (1944).

*15. FARMVILLE, PITT CO., N. C. Elev. 80 ft. Depth 472 ft.

0– 28	S. and cl.	Pleis.	
– 92	Blue cl. and sh.	Miocene	Yorktown
–465	S. and cl.	Up. Cret.	Tuscaloosa?
–472	Granite	Pre-Camb.?	

No samples; after Mundorff (1944).

*16. MARSDEN, BEAUFORT CO., N. C.

Norfolk Southern RR.; drilled 1917 Elev. 15± ft. Depth 149 ft.

0– 15		Pleis.	
–100		Miocene	Yorktown
–149		"	Trent

No samples; log from Norfolk Southern Railroad.

*17. WASHINGTON, BEAUFORT CO., N. C. Elev. 6 ft. Depth 400 ft.

0– 10	S., cl.	Pleis.	Pamlico
– 20	S., sh.	Miocene	Yorktown
– 96	Ls.	"	Trent
–135	Black s.	Eocene?	Castle Hayne?
–249	Ls., cl.	"	Castle Hayne?
–294	Sandy cl., sh.	?	?
–400	Blue clay	Up. Cret.	Peedee

No samples; after Mundorff (1944).

18. NEW BERN, CRAVEN CO., N. C.

Test well 8, 3 mi. W. New Bern Elev. 20 ft. Depth 198 ft. NCGS, ANSP

0– 35	S.	Pleis.	Pamlico
– 70	S., ls.	Miocene	Trent
–122	S., Bry., barnacles	Eocene	Castle Hayne
–198	Fine s.; forams.	"	Castle Hayne

18a. NEW BERN. A near-by well (No. 8).

0– 67	Ls.	Miocene	Trent
–102	Fine white s.	Eocene	Castle Hayne

18b. NEW BERN. Electric Light Plant. Well was drilled some years ago. Lower part of section (after Mundorff 1944).

354–645	S. and blue mud	Up. Cret.	Peedee
–929	Mud, s., sh., rock, wood	"	Black Creek

19. CHERRY POINT, CRAVEN CO., N. C.

U. S. Marine Air Base. Elev. 24 ft. Max. depth 340 ft. NCGS

Numerous wells at this Base. Best samples from wells 4, 15, 50, and 52, and isolated samples from wells 1, 2, 12, 19, 20, and 61. Following logs are typical.

Well No. 4, about 1¼ miles N. 35° E. of junction of U. S. Highway 70 and N. C. 101.

0– 50	S., cl., sh.	Pleis.	Pamlico
–100	S., cl., sh.	Pliocene	Croatan
–190	S., cl., sh.	Miocene	Yorktown
–288	S., ls.	"	Trent

Well No. 15, about 2.5 mi. N. 45° E. of junction of U. S. Highway 70 and N. C. 101.

0– 50	S., cl., and sh.	Pleis.	Pamlico
– 95	S., sh.	Pliocene	Croatan
–180	S., cl., and sh.	Miocene	Yorktown
–215	Ls.	"	Trent

Well No. 50, about 2¼ mi. due N. of junction.

0– 50±	S., cl., sh.	Pleis.	Pamlico
– 95	S., cl., sh.	Pliocene	Croatan
–118+	S., cl., sh.	Miocene	Yorktown
–285	No samples	—	
–290	Ls.	Miocene	Trent

Well No. 52, about 1¾ mi. due N. of junction.

0– 60	S., cl., sh.	Pleis. and Plio.	
–200	S., cl., sh.	Miocene	Yorktown
–323	Ls., s.	"	Trent
–340	Ls., s.	Eocene	Castle Hayne

Because of lithologic similarity of the Pamlico, Croatan, and Yorktown formations and because many shells may have fallen from higher levels, impossible to draw exact boundaries.

20. HAVELOCK, CRAVEN CO., N. C.
Great Lake Drilling Co. Elev. 30 ft. Depth 2,318 ft. USGS

0– 40		Pleis.	Pamlico
– 70		Plio.	Croatan
– 230		Miocene	Duplin
– 563		"	Trent
– 684		Eocene	Castle Hayne
–1,335		Up. Cret.	Peedee
–1,630		"	Black Creek continental
–2,125		"	Black Creek marine
–2,318		"	Tuscaloosa
– ?		Pre-Camb.	

Log adapted from Mansfield (1927). Restudy of samples discloses marine shells and Foraminifera in Tuscaloosa to base of well. No samples of basement rock available.

21. MOREHEAD CITY, CARTARET CO., N. C.
Outlying Airfield; well 63 Elev. 23 ft. Depth 224 ft. NCGS

0– 30	S. and sh.	Pleis.	Pamlico
– 97	S., ss., cl.	Pliocene	Croatan
		Miocene	Duplin-Yorktown
–150	S., cl., sh.	"	Duplin-Yorktown
–221	Ls.	"	Trent

22. FORT MACON, CARTARET CO., N. C.
State Park Elev. 10 ft. Depth 192 ft. NCGS

15– 70	S., cl., sh.	Pleis.	Pamlico
–188	S., cl., sh.	Pliocene	Croatan
		Miocene	Yorktown
–192	Ls.	Miocene	Trent

23. BOGUE, CARTARET CO., N. C.
Outlying Airfield; well 65 Elev. 18.5 ft. Depth 245 ft. NCGS

0– 40	Cl., sh. frag.	Pleis.	Pamlico
– 93	No samples	—	
–205	S., cl., sh.	Miocene	Yorktown-Duplin
–245	S., sh. frag., ls.	"	Trent

The fauna between 93 and 205 feet suggests the late Miocene equivalent to the Duplin or Yorktown. However, the presence of new species of *Glycymeris* and *Astarte* suggests that it may be a slightly different phase from that known in

outcrops. The presence of *Corbula chipolana*, as well as other species, shows a relationship to the Alum Bluff group of Florida which is slightly older than the Duplin.

24. ATLANTIC, CARTARET CO., N. C.
Outlying Airfield Elev. 15 ft. Depth 408 ft. NCGS

0– 30	S., sh.	Pleis.	Pamlico
–100±	S., ch., sh.	Plio.	Croatan
–330	Cl., some s., sh.	Miocene	Duplin
–408	Ls.	"	Trent

25. CAPE LOOKOUT, CARTARET CO., N. C. Elev. 8 ft. Depth 435 ft.

0– 75	No samples		
–100	S., sh.	Pleis. and Plio.	
–330	S., cl., sh.	Miocene	Yorktown
–415	S., cl.	"	?
–435	Ls., forams.	"	Trent

*26. LAKE LANDING, HYDE CO., N. C. Elev. 5 ft. Depth 200 ft.

6– 80	Pleis. and Plio.	
–100	Pliocene	Croatan
–200	Miocene	Yorktown

After Stephenson (1912); many fossils recorded.

27. KINSTON, LENOIR CO., N. C.
E. O. Johnson well; 1 mi. N. Kinston Elev. 80 ft. Depth 84 ft. NCGS

0–76	Green-gray s. and cl.	Up. Cret.	Peedee
–84	Greensand, sh.	"	Black Creek

Layer between 76 and 84 feet, containing *Lucina parva*, may present Snow Hill stage.

28. KINSTON, LENOIR CO., N. C.
Airport; wells 1 and 2 Elev. 80 ft. Max. depth 470 ft. NCGS

No. 1		No. 2		
0– 15	Cl.	0– 15	Pleis.	
–100	Gray s. and cl.	–100	Up. Cret.	Peedee
	Black and green cl.	–180	"	Peedee?
	S., sh., cl.	–407	"	Black Cr.
	S., cl., mica	–470	"	Tuscaloosa

Only identifiable fossil is *Lucina parva* between 184 and 218 feet.

29. GOLDSBORO, WAYNE CO., N. C.
Seymour Johnson Air Field Elev. 64 ft. Depth 180 ft. NCGS
Considerable variation in wells. Following is generalized log.

0– 15	S., cl.	Pleis.	
–100	S., cl., wood	Up. Cret.	Black Creek
–180	Cl.	"	Tuscaloosa
– ?	Basement rock	Pre-Camb.?	

30. POLLOCKSVILLE, JONES CO., N. C.
Auxiliary Air Base
3 mi. W. Pollocksville; well 66 Elev. 30 ft. Depth 300 ft.

0– 20	S.	Pleis.	
– 57	S., ls.	Miocene	Trent
–280	Ls., marl	Eocene	Castle Hayne
–300	Blue cl.	Up. Cret.	Peedee

Jackson Foraminifera identified by Cushman between 57 and 280 feet (Mundorff 1944).

31. JACKSONVILLE, ONSLOW CO., N. C.
R.E.A. well; E. side Northwest Creek on Highway 24 Elev. 30± ft. Depth 566 ft. NCGS

0– 38	S.	Pleis.	
– 73	Fine white s.	Plio.	Croatan
– 88	S., ls., sh.	Miocene	Trent
–253	Clay and marl	Eocene	Castle Hayne
–566	S., cl., forams.	Up. Cret.	Peedee

Cushman reported highest Cretaceous fossils at 260 feet (Mundorff 1944).

32. JACKSONVILLE, ONSLOW CO., N. C.
Tent Camp area Elev. 30± ft. Depth 184 ft. NCGS

0– 30	Sandy cl.	Pleis.	
–105	Sandy cl., ls.	Miocene	Trent
–184	Ls.	Eocene?	Castle Hayne?

33. JACKSONVILLE, ONSLOW CO., N. C.
Layne Housing Project, W. of town Elev. 30± ft. Depth 153 ft. NCGS

34– 63	S., sh.	Plio.	Croatan
–132	Ls.	Miocene	Trent
–153	Ls., cl.	Eocene	Castle Hayne

34. CAMP LEJEUNE, ONSLOW CO., N. C.
Marine Base Elev. 30± ft. Max depth 567 ft. NCGS
Test well No. 1, 1 mi. SE. Jacksonville.

0– 10	Clayey s.	Plio.	Croatan
–227	S., ls.	Miocene	Trent

Test well No. 4, 10 mi. SE. Jacksonville, near Cowhead Creek.

0– 78	S.	Pleis. and Plio.	
–116	S., sh. frag.	Miocene?	Duplin?
–145	Ls.	Miocene	Trent
–414	S., ls.	Eocene	Castle Hayne
–567	S., cl.	Up. Cret.?	Peedee?

35. SEARS LANDING, CAMP DAVIS, ONSLOW CO., N. C. Elev. 8± ft. Depth 212 ft.

0– 40	S., sh.	Recent and Pleis.	
–120	S., cl., sh.	Pleis., Plio., and Miocene	
–211	S., cl., ls., Bry.	Eocene	Castle Hayne

36. HOLLY RIDGE, ONSLOW CO., N. C.
Opposite Camp Davis Elev. 60 ft. Depth 176 ft. NCGS

0–126	S.	Pleis., Plio. and Miocene	
–180	Ls., sh., Bry.	Eocene	Castle Hayne

It is frequently difficult to separate the Trent from the Castle Hayne on either lithology or macrofossils. Berry (1941) gives the log of a well at Camp Davis and records Trent between 135 and 148 feet. However, the writer is inclined to doubt the presence of the Trent in the Camp Davis area.

37. TOP SAIL INLET, PENDER CO., N. C.
U. S. Army Elev. 8 ft. Depth 197 ft.

0– 15	Beach s.	Recent	
– 73	S., cl., sh.	Miocene	Yorktown
–172	S., ls., sh., Bry.	Eocene	Castle Hayne
–197	S., sh. frag.	Eocene?	

38. WILMINGTON, NEW HANOVER CO., N. C.
Bomber Base; 3 mi. E. Wilmington Elev. 40 ft. Max. depth 105 ft. NCGS

1	2	3			
0– 50	0– 60	0– 58	S., some cl.	Pleis. and older?	
–105	–102	– 96	S., gr., ls.	Up. Cret.	Peedee

Numerous casts of *Cardium penderense* in Peedee limestone.

39. WILMINGTON, NEW HANOVER CO., N. C.
Housing Authority; 4 mi. S. Wilmington Elev. 60 ft. Max. depth 161 ft. NCGS

Well 1	Well 2			
0– 57	0– 58	S., cl.	Pleis. and older?	
– 87	–102	Sandy cl., ls. Bry.	Eocene	Castle Hayne
	–186	Cl., s., Bry.	Up. Cret.	Peedee

Castle Hayne characterized by Bryozoa *Lunularia distans*.

40. WILMINGTON, NEW HANOVER CO., N. C.
Hilton Park; Clarendon Water Works Elev. 9 ft. Depth 1,330 ft. NCSM; ANSP

This well was studied by Stephenson (1912, pp. 163–66). A restudy of the samples suggests that the lower part of the Cretaceous (referred to the Black Creek by Stephenson) may represent the Tuscaloosa.

0– 720	Up. Cret.	Peedee
–1,087	"	Black Creek
–1,109	"	Tuscaloosa; no fossils
–1,330	Pre-Camb.	

*41. FORT CASWELL, NEW HANOVER CO., N. C. Elev. 10 ft. Depth 1,543 ft.

This well was also studied by Stephenson (1912, pp. 169–70). Although the samples are not available at the present time, a restudy of the log suggests that the Tuscaloosa is represented by the lower part of the Cretaceous section.

0– 78	Pleis.	
– 254	Eocene	Castle Hayne
–1,140	Up. Cret.	Peedee
–1,455	"	Black Creek
–1,540	"	Tuscaloosa
–1,543	Pre-Camb.	

42. MAXTON GLIDER BASE, SCOTLAND CO., N. C.
3 mi. NW. Maxton, Robeson Co. Elev. 210 ft. Depth 448 ft. NCGS

0– 12	Sandy cl.	Pleis	
–363	S., cl., no fossils	Up. Cret.	Tuscaloosa
–448	Schist	Pre-Camb.	(?)

*43. TABOR CITY, COLUMBUS CO., N. C.
Virginia Machine & Well Co. (1926) Elev. 105 ft. Depth 675 ft.

0–221	Marl, s.	Up. Cret.	Peedee
–551	Clay, some s.	"	Black Creek
–675	White and blue cl.	"	Tuscaloosa

No samples. After Mundorff (1944).

44. FAIRMONT, ROBESON CO., N. C. Elev. 140 ft. Depth 380 ft. NCGS

0– 15	Red cl., s	Pleis.	
–356	Clay, lignitized wood	Up. Cret.	Black Creek
–380	Varicolored cl.	"	Tuscaloosa

South Carolina

There are no extensive collections of well samples from South Carolina. The material consulted came from the Georgia Geological Survey, the United States Geological Survey, the Woolman Collection, the Sun Oil Company, and several local sources. The writer is indebted to James McLean, Jr., of Parris Island, South Carolina, for many samples and data of the deep well at the Marine Base.

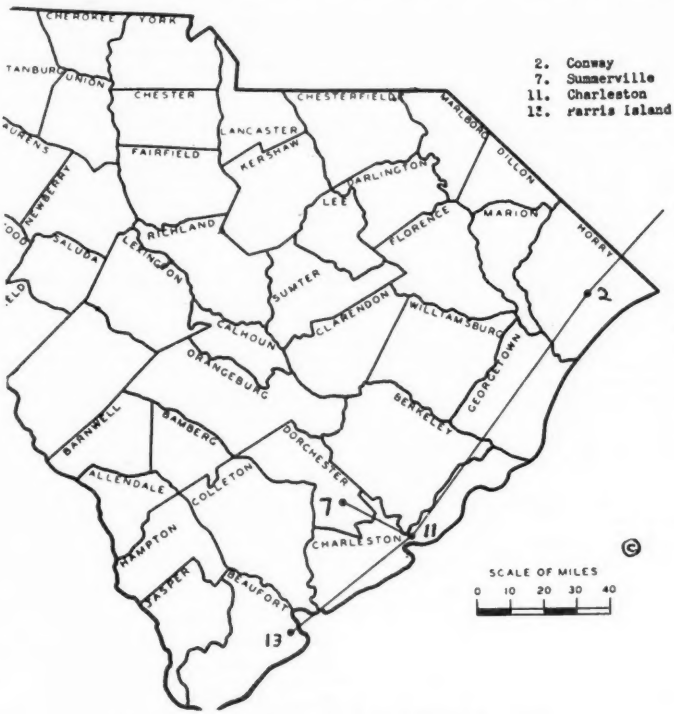

FIG. 7.—Outline map of part of South Carolina.

The logs of several South Carolina wells are given by Cooke (1936).

*1. ALLSBROOKS, HORRY CO., S. C.
Palmetto Drilling Co., 1 mi. N. Allsbrooks Elev. 107 ft. Depth 1,150 ft.

The following information was received from a resident of Conway, South Carolina.

Wells drilled by the Palmetto Drilling Company were as follows: One well about fifty yards west of the railroad and three-fourths of a mile north of Allsbrooks, on the Allsbrooks Farm in Horry County. One well about one mile south of Allsbrooks and about two hundred yards east of the railroad on the Tyler Farm. The Allsbrooks wells produced no oil

although there was considerable show of gas in the soil, but not in quantity. There is some seepage of oil to the top of the earth in occasional spots in this vicinity.

According to reports, bed rock was struck at 1,150 feet. The wells were drilled in 1939.

2. NEAR CONWAY, HORRY Co., S. C.
Pioneer Oil Co.; Smart Farm, 12 mi. SW. Conway — Elev. 31 ft. — Depth 1,429 ft. — SUN

50– 450	Greenish s.	Up. Cret.	Peedee
– 460	S., sh.	"	Snow Hill
–1,040	S., sh. frag.	"	Black Creek
–1,400	Green and white s., sh. frag.	"	Tuscaloosa
–1,429	Bed rock	Pre-Camb.	

3. NEAR CONWAY, HORRY Co., S. C.
Pioneer Oil Co.; Hucks No. 1, E. side Peedee River, 2 mi. NW. Smart Farm
Elev. 25 ft. — Depth 1,375 ft. — SUN

80– 510	Greenish s.	Up. Cret.	Peedee
–1,040	S., sh.	"	Black Creek
–1,375	S., sh. frag.	"	Tuscaloosa?
– —	Rock	Pre-Camb.	

4. NEAR GEORGETOWN, GEORGETOWN Co., S. C.
Southern States Drilling Co's. Lee Williams No. 1, 28 mi. N. of Georgetown on Route 51
Elev. 46 ft. — Depth 1,397 ft. — SUN

100– 955	S., sh., lignite	Up. Cret.	Black Creek
–1,397	White s., cl., pinkish near bottom	"	Tuscaloosa

5. RHEIMS, WILLIAMSBURG Co., S. C.
Southern States Drilling Co. — Elev. 40 ft. — Depth 825 ft. — SUN

0–415	No samples	—	
–520	S., sh.	Up. Cret.	Peedee
–825	S., sh. frag.	"	Black Creek

6. MONCKS CORNERS, BERKELEY Co., S. C.
Intransit Depot; U. S. Army — Elev. 53 ft. — Depth 177 ft. — ANSP

0–132	Cl., some s.	Miocene	
–177	Ls., sh. (Pecten)	Eocene	Santee-Cooper

*7. SUMMERVILLE, DORCHESTER Co., S. C.
Oil prospecting well — Elev. 71 ft. — Depth 2,470 ft.

5– 8	Miocene	Duplin
– 37½	"	Hawthorne
– 313	Eocene	Cooper-Santee
– 600?	"	
–1,675	Up. Cret.	Peedee-Black Creek
–2,450	"	Tuscaloosa?
–2,470	Pre-Camb.	

This log is from Mansfield (1937), modified from Cooke (1936, p. 177). Cooke regarded the section between 1,580 and 2,470 feet as Triassic (Newark series) and recorded diabase at 1,630–1,645 and at 2,450–2,470. Mansfield regards the section as Cretaceous but says nothing about the diabase at 1,630–1,645, though he mentions a crystalline basement at 2,450 feet. No samples are available.

*8. MULLINS, MARION Co., S. C. — Elev. 103 ft. — Depth 657 ft.

0–470	Cl., s.	Up. Cret.	Black Creek
–657	Pink and white cl., s.	"	Tuscaloosa

Log after Virginia Well and Machine Company and M. J. Mundorff.

*9. FLORENCE, FLORENCE CO., S. C. Elev. 142 ft. Depth 1,750 ft.

0– 61	Sandy cl. and gr.	Pleis.	Sunderland
– 205	Black shaly cl. and s.	Up. Cret.	Black Creek
– 603	Light-colored micaceous s., cl.	"	Tuscaloosa
–1,335	Sandstone	Triassic	Newark
– ?	"Black rock"=dike?	"	Newark

Upper part of log from Cooke (1936, p. 178); lower part from Darton (1896, p. 218). No samples available.

*10. WALTERBORO, COLLETON CO., S. C. Elev. 65 ft. Depth 1,500 ft.

0– 60	S.	Miocene	Hawthorne and younger
– 560	Marl, ls.	Eocene	Cooper-Santee
– 750	Cl., marl, ls.	Up. Cret.	Peedee?
–1,500	Cl., s.	"	Black Creek

From Cooke (1936, p. 174).

11. CHARLESTON, CHARLESTON CO., S. C. Elev. 10 ft. Depth 2,015 ft. LW

0– 75		Pleis.	
– 83		Plio.	
– 220		Eocene	Cooper
– 447		"	Santee
– 742		Eocene or Up. Cret.	(no fossils)
–1,550		Up. Cret.	Peedee
–1,723		"	Black Creek?
–2,015		"	Black Creek

After Stephenson (1914). The published log goes only to 2,007 feet, but the Woolman collection contains samples to 2,015 feet with fossils present in the lowest layer (1,985–2,015 feet).

A water well was drilled in 1943 at the Charleston Navy Yard to a depth of 2,136 feet, but unfortunately no samples were saved.

12. FORT MOULTRIE, CHARLESTON CO., S. C. Elev. 5 ft. Depth 1,800 ft.

A single sample, between 1,600 and 1,800 feet supplied by W. S. Beiser of Layne Atlantic Company at Savannah, Georgia, contained *Ostrea* sp., probably referable to the Black Creek.

13. PARRIS ISLAND, BEAUFORT CO., S. C.
U. S. Marine Base; well 2 Elev. 18 ft. Depth 3,454 ft. USGS, GaGS, ANSP, FlaS.

0– 100	No samples (see well 15)		
– 650	Ls.	Eocene	Ocala
– 875±	Ss.	"	McBean=Claiborne
–1,165	Ls.	"	Black Mingo?=Wilcox
–1,335	Forams.	"	Midway
–1,925	Med. gray silt, cl., sh. frag.	Up. Cret.	Peedee
–2,395		"	Black Creek
–2,670	Cl. and ss.	"	Eutaw?
–3,115	Cl.	"	Tuscaloosa
–3,245	Cl., some s., sh., forams.	"	Marine Tuscaloosa
–3,454	Cl., some s.	"	Tuscaloosa

This log is partly based on a report by J. B. Reeside, Jr., which is on file at the Georgia Geological Survey in Atlanta, and which was consulted by permission of Garland Peyton, director. It is also based on information supplied by several oil geologists and on the study of the samples by the writer. There seems

to be general agreement about the thickness of the Ocala, but the divisions of the earlier Eocene are less certain, being based on foraminiferal identifications by J. A. Cushman (quoted by Reeside) and some oil geologists. The division of the Upper Cretaceous into Peedee, Black Creek, and Eutaw (?) is tentative, also being based largely on foraminiferal studies. The section between 2,395 and 2,670 feet is more sandy and is correlated with the Eutaw or Austin. Munyan (1943) also discusses the lower part of this well.

The most notable feature of this well is the presence of a marine phase of the Tuscaloosa with Foraminifera and Mollusca including *Exogyra* n. sp.

14. PARRIS ISLAND, BEAUFORT CO., S. C. Elev. 18 ft. Max. depth 2,294 ft. ANSP
Samples from other wells in Parris Island area received from James McLean. Log is based on preliminary studies of fossils from upper levels.

100– 670	Eocene	Ocala
670–1,440	"	Wilcox and Midway
2,203–2,294+	Up. Cret.	

15. PARRIS ISLAND, BEAUFORT CO., S. C.
Test well (1944) Elev. 18 ft. Depth 715 ft. ANSP

0– 60	Pleis.	Pamlico
– 75	Plio.	Waccamaw
–715	Eocene	Ocala

GEORGIA

The writer was permitted to examine the collection of well samples of the Department of Mines, Mining and Geology of the State of Georgia at Atlanta, Georgia. This coöperation was arranged by Garland Peyton and A. S. Furcron. In addition help was received from M. A. Warren and Stephen Herrick of the United States Geological Survey assigned to Georgia.

Various publications have been issued on the subsurface geology of Georgia, notably by Stephenson and Veatch (1915), Prettyman and Cave (1923) and more recently by Applin and Applin (1944). In addition, various mimeographed reports on well logs have been issued by the Department of Mines, Mining and Geology in Atlanta.

1. SAVANNAH, CHATHAM CO., GA.
Breckenridge well, 2.5 mi. S. Savannah Elev. 32 ft. Depth 600 ft. GaGS

0–130	S., gr.	Pleis.	
–275	Silt and cl.	Miocene	Alum Bluff
–600	Ls., Bry., sh., forams.	Eocene	Ocala

The Bryozoa between 375 and 600 feet include *Schizopodrella viminea* Lonsdale, an index fossil of the middle and upper Jackson. Among other species are *Stamenocella* sp., *Floridina* sp. and *Membranipora spissumuralis* Canu & Bassler, identified by R. S. Bassler.

Most of the mollusks in the Ocala are indeterminable as to species although the following genera can be recognized: *Nucula, Cardium, Crassatella, Turritella, Pecten, Ostrea, Phacoides.* In the Savannah well between 500 and 520 feet, *Pecten cookei* and *Nucula* n. sp. near *ovula* were recognized.

2. CHEROKEE HILL, CHATHAN CO., GA.

Oil test; 6 mi. NW. Savannah Elev. 22 ft. Depth 2,130 ft. GaGS

0– 240	No samples		
– 950	Ls., Jackson Bry.	Eocene	Ocala
–1,400	Marl, cl.	"	McBean Claiborne
–1,560	Marl, cl.	"	Black Mingo? Wilcox
–1,730	Marl, cl.	"	Midway
–2,130	Marl, cl., some s.	Up. Cret.	Ripley

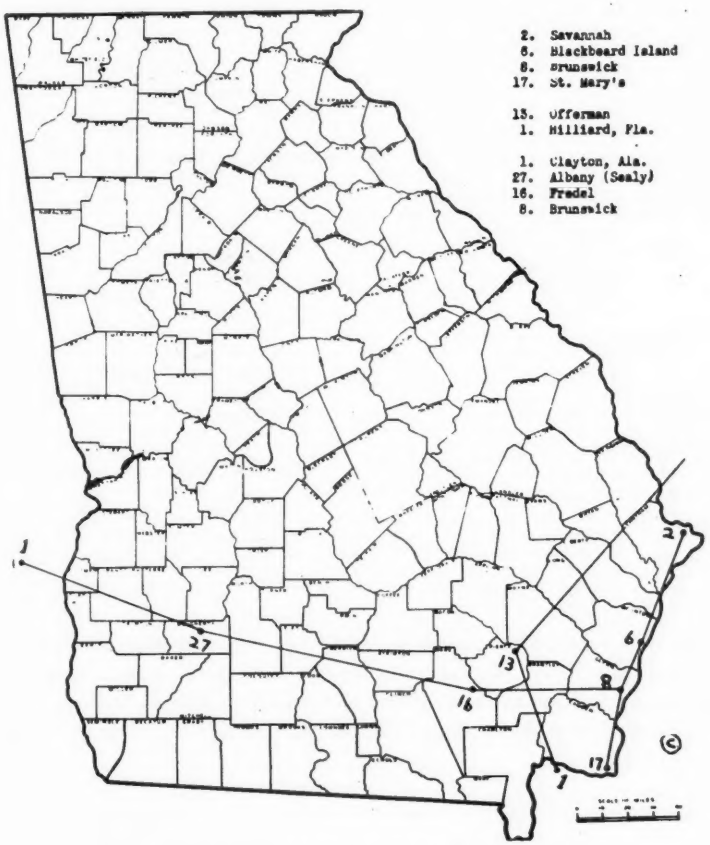

FIG. 8.—Outline map of Georgia. Scale, $\frac{5}{8}$ inch = 40 miles.

For detailed log see Prettyman and Cave (1923, pp. 94–97). Jackson Bryozoa were identified by Bassler at 710–740 feet and 800–810 feet. *Belemnitella americana* was reported from 1,940 feet (Prettyman and Cave). Subdivisions of the Eocene are based on studies on Foraminifera by oil geologists.

3. FORT SCREVAN, CHATHAM CO., GA.
Northern part Tybee Island — Elev. 12 ft. — Depth 610 ft. — GaGS

0–158	S., sh.	Pleis.	Pamlico
–220	S., ls.	Miocene	
–610	Ls., Bry.	Eocene	Ocala

4. WAY STATION, BRYAN CO., GA.
Richmond Hill; Ford Farm — Elev. 12 ft. — Depth 450 ft. — GaGS

0–350	S., cl., no fossils	—	
–450	Ls., Bry.	Eocene	Ocala

5. CAMP STEWART, LIBERTY CO., GA.
Well 161; 1.6 mi. NW. Courthouse — Elev. 90 ft. — Depth 816 ft. — GaGS

0–435	S., cl., gr.	Miocene and younger	
–816	Ls., Bry., forams.	Eocene	Ocala

Kleidionella lobata Canu & Bassler at 531 feet, identified by R. S. Bassler.

6. BLACKBEARD ISLAND, MCINTOSH CO., GA.
U. S. Fish and Wild Life — Elev. 10 ft. — Depth 711 ft. — GaGS

0–355	No samples		
–424	S., ls., sh. frag.	Miocene?	
–645	Ls., some Bry.	Eocene	Ocala
–711	Calcareous s.	"	Ocala?

7. ST. SIMONS ISLAND, GLYNN CO., GA.
U. S. Naval Air Station — Elev. 15 ft. — Depth 694 ft. — GaGS

0– 40	S., gr. sh.	Pleis.	Pamlico
–395	S., cl.	Miocene	Alum Bluff?
–694	Ls., Bry., sh.	Eocene	Ocala

8. BRUNSWICK, GLYNN CO., GA.
Hercules Powder Co. — Elev. 10 ft. — Depth 1,063 ft. — GaGS

0– 200	No samples		
– 300	S., cl., sh.	Miocene	Alum Bluff
– 405	S., ls., sh.	"	?
– 560	S., ls., sh. casts	"	Tampa
– 795	Ls., Bry., forams.	Eocene	Ocala
–1,063	Ls., Bry., forams.	"	Ocala or Claiborne

Good Jacksonian Bryozoa are found at 595 feet (Bassler). Similar Bryozoa extend to the bottom of the well and suggest a thick Jackson section. This is confirmed by the Jackson mollusk, *Pecten* (*Amusium*) *ocellanum* Dall, at 1,010 feet. However, some oil geologists have identified Claiborne Foraminifera between 795 and 1,063 feet.

9. BRUNSWICK, GLYNN CO., GA.
Naval Air Station, 6.2 mi. N. Brunswick — Elev. 24 ft. — Depth 986 ft. — GaGS

0–134	S., some gr., sh. frag.	Pleis.	Pamlico
–204	S., sh. frag.	Plio. or Miocene	
–609	S., cl., sh. frag.	Miocene	Alum Bluff
–986	Ls.	Eocene	Ocala

10. NAHUNTA, BRANTLEY CO., GA.
City wells — Elev. 63 ft. — Depth 648 ft. — GaGS

0–547	S., cl., no fossils	Miocene and later	
–648	Ls., forams.	Eocene	Ocala

11. BAXLEY, APPLING CO., GA.
City well Elev. 204 ft. Depth 849 ft. GaGS

0–500	S., cl.	Miocene and later	
–849	Ls., Bry., sh. frag., forams.	Eocene	Ocala

*12. OFFERMAN, PIERCE CO., GA.
Pan American-Adams McGaskill; 1.5 mi. E. Offerman Elev. 77 ft. Depth 4,375 ft. GaGS

A log and preliminary study of the macrofossils was prepared by Mrs. E. R. Applin for the Georgia Survey. Later Munyan (1943) studied some of the samples and recognized the marine Tuscaloosa between 4,238 and 4,355 feet.

*13. OFFERMAN, PIERCE CO., GA.
Donald Clark-Adams McGaskill; 2.3 mi. E. Offerman Elev. 77 ft. Depth 4,355 ft.

The following year another oil test was drilled near Offerman. The samples from both wells have been studied by numerous geologists. The following table is based on a recent report by Applin and Applin (1944, p. 1744).

0– 111	No samples	
– 639	Miocene	
– 701	Oligocene	
– 887	Eocene	Ocala
–1,841	Late Mid. Eocene (non-fossiliferous	Claiborne
–2,028	Early Mid. Eocene	Lake City ls.
–2,384?	Low. Eocene	Oldsman ls.? = Wilcox
–3,022	Beds of Mid-way age	
–3,384	Up. Cret.	Beds of Navarro age = Ripley
–3,495	"	Beds of Taylor age
–3,870	"	Beds of Austin age = Eutaw
–4,260	"	Tuscaloosa formation
–4,335	Low. Cret.	
–4,355	Pre-Camb.	Granite

14. UVALDA, MONTGOMERY CO., GA.
Meadows Development Co. No. 2 Elev. 199 ft. Depth 1,619 ft. GaGS

Core samples were examined at the Georgia Survey in Atlanta, but no macrofossils were observed. A log (without correlations) is included in a mimeographed report by the Georgia Survey. Later information obtained from some oil geologists, now on file in Atlanta, gives the following.

642	Top of Ocala
982	Top of McBean
1,619	Total depth

15. SOPERTON, TREUTLEN CO., GA.
Glen Rose Oil Co's. Fowler No. 1, 6 mi. W. Soperton Elev. 291 ft. Depth 2,125 ft. GaGS

0– 565	Samples not available	Miocene and later	
– 595	Samples not available	Oligocene	Flint River
– 695	Ls.	Eocene	Ocala
–1,075	Ls., sh. frag., Bry.	"	McBean
–1,495	Ls., s., gr.	"	Wilcox
1,675	S. and fine gr.	Up. Cret.	
–2,125	S., gr.	"	Eutaw

No macrofossils were observed; these correlations are from oil geologists, on file at Georgia Survey.

16. FREDEL, WARE CO., GA.

Waycross Oil Co., 10 mi. S. Waycross		Elev. 100 ft.	Depth 2,978 ft.	GaGS
0– 435	S., cl. (no samples available)	Miocene	Hawthorne	
– 800	Ls. (no samples available)	"	Tampa	
–1,120?	Ls.	Eocene	Ocala	
–1,891	Ls., forams.	"	Claiborne	
1,891	Ls. top	"	Wilcox	
–2,978	Ls., s. at base	"		

For a detailed log, see Prettyman and Cave (1923, pp. 98–101). No macrofossils were observed in the samples examined. The considerable thickness of the Eocene (2,178 feet) is noteworthy. Eocene subdivisions from data obtained from oil geologists.

17. ST. MARY'S, CAMDEN CO., GA.

Kraft Corp.		Elev. 12 ft.	Depth 1,060 ft.	GaGS
0– 30	S.		Pleis.	
–540	S., some cl., sh.		Miocene	Alum Bluff
–960	Ls., Bry., forams.		Eocene	Ocala

Jacksonian Bryozoa (*Schizopodrella viminea* Lonsdale, *Stamenocella* and *Floridina*) were found between 560 and 940 feet; *Coskinilina floridina* (foram.) was found at 1,030 feet.

18. HOMERVILLE, CLINCH CO., GA.

Georgia Resources Co's. Gillican No. 1, 17 mi. S. Homerville
Elev. 135 ft. Depth 1,507 ft. GaGS

Log by C. W. Deming and micropaleontology by Winnie McGlamery were included in a report mimeographed by the Georgia Survey (1941). The well stopped in the Wilcox.

19. VALDOSTA, LOWNDES CO., GA.

Test well No. 1		Elev. 215 ft.	Depth 425 ft.	GaGS
0–260	Cl., s.			
–425	Ls., forams., sh. casts		Eocene	Ocala

The Ocala mollusks were not identifiable as to species, although several genera were represented.

20. THOMASVILLE, THOMAS CO., GA.

8 mi. NE. town		Elev. 233 ft.	Depth 420 ft.	GaGS
0– 60	Cl.		Miocene	Alum Bluff
–420	Cl., ls., Bry., forams., sh.		Miocene	Tampa
			Oligocene	Vicksburg
			Eocene	Ocala

*21. MEIGS, THOMAS CO., GA. Elev. 347 ft. Depth 1,530 ft.

The base of the well is in the Eocene. A preliminary report on the Foraminifera was prepared by E. R. Applin (report mimeographed by Georgia Geol. Survey, 1941).

*22. HAZELHURST, JEFF DAVIS CO., GA.
Middle Georgia Oil and Gas Co., 12 mi. W. Hazelhurst Elev. 225 ft. Depth 1,975 ft.

0– 690	S., cl.	Miocene	Alum Bluff
–1,115	Ls., forams.	Eocene	Ocala, possibly some Glendon
–1,300	S.	"	McBean
–1,975	S. and marl	Eocene or Up. Cret.	

This log is slightly modified from Prettyman and Cave (1923, pp. 102–05). According to this report the bottom of the well is in the Ripley; however, some oil geologists believe that the well did not reach the Cretaceous.

23. ADEL, COOK CO., GA.
City Water Plant Elev. 240 ft. Depth 358 ft. GaGS

0– 90	S., cl.	Miocene	Alum Bluff
–270	Ls.	Miocene or Eocene	Tampa or Ocala
–358	No samples		

24. GRACEWOOD, RICHMOND CO., GA.
Georgia Training School Elev. 136 ft. Depth 1,200 ft. GaGS

0– 325	Cl., s.	Up. Cret.	
–1,200	Talcose schist	Pre-Camb.	

25. AUGUSTA, RICHMOND CO., GA.
Circular Court, 6.5 mi. S. Augusta Elev. 156 ft. Depth 329 ft.

0–175	Cl., some s.	Up. Cret.	
–329	Talcose schist	Pre-Camb.	

26. ALBANY, DAUGHTERY CO., GA.
Well No. 7 Elev. 200 ft. Depth 1,200 ft.

0– 340±	Ls.	Eocene	Ocala
– 487?	Ls., calcareous cl.	"	Claiborne
– 645	Sandy marl, cl.	"	Wilcox
– 912	Ls.	"	Midway
–1,200	S., some glauc., forams.	Up. Cret.	Ripley

At the present time samples are available only from 27 to 340 feet and the lower section is from Winnie McGlamery (mimeographed report of Georgia Survey).

The following Bryozoa were identified by R. S. Bassler: *Metradolius obliquum* C&B (230–236 feet), *Tubucella monilifera* C&B (230–236 feet) and *Kleidonella lobata* C&B (308–340 feet). All are middle Jacksonian (Bassler).

Mollusk fragments included *Turritella* sp. (112–115 feet), *Ostrea divaricata* Lea (?) (323–332 feet), and *Pecten* sp. (326–332 feet).

See Prettyman and Cave (1923, pp. 93–94) for log of Albany No. 2.

27. 7 MILES W. OF ALBANY, DAUGHTERY CO., GA.
J. R. Sealy's Reynolds Bros. Lumber Co. No. 1 Elev. 196 ft. Depth 5,013 ft. GaGS, ANSP

0– 205	No samples	Eocene	Ocala
– 440	S., some cl., gr., sh. frag.	"	Claiborne
– 623	Ls., s.	"	Wilcox
– 925	Ls., s., sh. frag.	"	Midway
–1,045	S., cl., some glauc.	Up. Cret.	Ripley
–1,585	S., cl., some glauc.	"	Selma
–2,380	S., cl., some glauc.	"	Eutaw
–2,800	S., cl., no fossils	"	Tuscaloosa
–5,013	S., cl., glauc., many fossils	"	Tuscaloosa

Eocene subdivisions based largely on microfossils obtained from oil geologists (now on file in Atlanta). The great thickness of the marine Tuscaloosa is noteworthy. Marine shells are common throughout almost the entire section (2,213 feet), although it is possible that some may have washed down from above. However, a careful log, prepared by A. S. Furcron at the time of the drilling, records marine fossils in the core from about 2,800 feet to the bottom of the well.

The Tuscaloosa fauna includes *Nodosaria affinis* and other Foraminifera not yet identified, also the following macrofossils: *Pecten* n. sp., *Ostrea* n. sp., *Teredo* sp., *Hamulus* n. sp.

OTHER OIL TESTS

The following is a partial list of the oil test wells drilled in the Coastal Plain of Georgia. It is taken partly from Prettyman and Cave (1923), Postley (1938), and personal communications from the Department of Mines, Mining and Geology of Georgia. So far, none of the tests has yielded oil in commercial quantities.

	Year		*Depth in Feet*
1.	1905–07	3.5 mi. SW. Louisville, Jefferson Co. Drilled by A. F. Lucas; deepened by Georgia Resources Co.	1,143
2.	1905–06	Doctortown, Wayne Co.	1,901
3.	1908	Hazelhurst, Jeff Davis Co. Hinson Oil Gas & Development Co.	985
4.	1915	Near Fredel, Ware Co. Waycross Oil & Gas Co.; two wells, one in Ware County, and one in Charlton County	3,045
5.	1919	9 mi. NW. Fitzgerald, Hill Co.	830
6.	1920	12 mi. NW. Sandersville, Washington Co. Middle Georgia Oil & Gas Co.; reached crystalline rocks	400±
7.	1920	15 mi. W. Hazelhurst, Jeff Davis Co. Middle Georgia Oil & Gas Co.	1,975
8.	1920	Cherokee Hill, 6 mi. NW. Savannah, Chatham Co. Savannah Oil & Gas Co.	2,130
9.	1921	Allens Station, 9 mi. S. Augusta, Richmond Co. Three Creeks Oil Co.; reached crystalline rocks at 400 feet	400
10.	1921–23	2.5 mi. E. Green Cut, Burke Co. Three Creeks Oil Co.; struck crystalline rocks at 1,002 feet, Tuscaloosa at 406 feet	1,033
11.	1923	In Wheeler Co., near McRae, Telfair Co. Dixie Oil Co.; top of Ocala, 680 feet; top of Cretaceous, 1,915 feet	3,384
12.	1923?	Scotland, Telfair Co.	—?
13.		Town Bluff Ferry, Jeff Davis Co. Altamaha Oil & Gas Co.	1,105
14.	1932	Graymont, Emanuel Co. Georgia Oil Co.	2,332
15.	1938	1.5 mi. E. Offerman, Pierce Co. Pan American's Adams McGaskill	4,375
16.	1939	2.3 mi. E. Offerman, Pierce Co. Donald Clark's Adams McGaskill	4,355
17.	1939	Uvalda, Montgomery Co. Meadows Development Co.	1,619
18.	1939	Vidalia, Tooms Co. Meadows Development Co. No. 1	1,562
19.	1939	Homerville, Clinch Co. Georgia Resources' Gillican's No. 1	1,507
20.		6 mi. SW. Soperton, Treutlen Co. Glen Rose Oil Co's. James Fowler No. 1	2,125
21.	1942	Near Albany, Daughtery Co. J. R. Sealy No. 1	5,013
22.	1943	Near Albany, Daughtery Co. J. R. Sealy No. 2	5,000±
23.	1943	7 mi. NE. Douglas, Coffee Co.	1,200
24.	1943	3 mi. SW. Cedar Springs, Early Co. Mont Warren *et al.* Chandler No. 1	7,240
25.	1943	Near Jessup, Wayne Co.	400+
26.	1944	5 mi. SE. Homerville, Clinch Co. Hunt Oil Co's. Musgrove	4,110
27.	1944	6 mi. S. Bainbridge, Decatur Co. H. Hunt Co.	—
28.	1944	10 mi. SE. Camilla, Mitchell Co. Stanolind's Pullen No. 1	7,488
29.	1944	6.8 mi. E. McKinnon, Wayne Co. California Co's. Brunswick Peninsula	4,575
30.	1944	6.6 mi. SW. Pearson, Atkinson Co. Sun Oil Co's. Doster-Ladison No. 1	4,283

Alabama

While Alabama lies outside the scope of the present study, samples from a few wells were studied for comparison with those from Georgia and other states. Some Alabama material is in the collection of the Georgia Survey and was examined in Atlanta, and a complete set is at the Geological Survey of Alabama at Tuscaloosa, and was examined through the kindness of Miss Winnie McGlamery, State paleontologist. A few notes on selected wells are given herewith.

A compilation of logs of many oil tests and deep water wells is given by Bowles (1941).

*1. Near Clayton, Barbour Co., Ala.
W. B. Hinton's Creel No. 1, oil test, Sec. 19, T. 9 N., R. 26 E.
Elev. 504 ft. Depth 5,572 ft. AlaGS
Summary from Miss McGlamery (personal communication).

0– 191	Eocene	Clayton
–1,735	Up. Cret.	Ripley and Blufftown
–2,450±	"	Eutaw
–3,721±	"	Tuscaloosa
–4,438	Low. Cret.	
–5,372	Triassic(?)	

No marine Tuscaloosa was observed. See Munyan (1943).

2. Near Clayton, Barbour Co., Ala.
H. A. Stebinger's Robertson No. 1, oil test, Sec. 19, T. 10 N., R. 26 E.
Elev. 554 ft. Depth 5,260 ft. GaGS; AlaS

No detailed log is available. Samples at the Georgia Survey in Atlanta contained the following fossils: *Corbula crassiplicata* (1,709–1,740 feet) and *Ostrea* sp., *Hamulus* n. sp. (2,204–2,235 feet). These are probably post-Tuscaloosa, and may be Eutaw or Ripley.

3. Near Bladen Springs, Choctaw Co., Ala.
McCorvey No. 1, oil test, Sec. 20, T. 9 N., R. 2 W. Elev. 120 ft. Depth 9,626 ft. AlaGS

0– 170	No samples	
– 200	Eocene	Hatchetigbee
– 290	"	Bashi
– 890	"	Tuscahoma
–1,480	"	Nanafalia; Salt Mountain 890–970± feet
–1,877	"	Midway
–2,914	Up. Cret.	Selma
–3,464	"	Eutaw
–5,460	"	Tuscaloosa; 4,120–4,300 marine
–7,500	Low. Cret.	
–9,626	No samples	

This log is from Miss McGlamery (personal communication). The Eocene macrofossils included: *Ostrea thirsae* (1,000–1,008 feet), *Turritella nasuta* var. (1,400–1,420 feet), and *Cadulus turgidus* (1,660–1,680 feet).

The marine Tuscaloosa included some poorly preserved gastropods tentatively referred to *Nerita* or *Avelana*. Some Foraminifera were identified by Miss McGlamery as *Ammobaculites* and *Haplophragmoides*.

4. Scotch Lumber Company, Clarke Co., Ala.
Magnolia Petroleum Co., Sec. 17, T. 10 N., R. 3 E. Elev. 354 ft. Depth 5,998 ft.
Log from Miss McGlamery (personal communication).

0– 205	No samples	
–1,329	Eocene	Wilcox
–1,725	"	Midway
–2,833	Up. Cret.	Selma
–3,422±	"	Eutaw
–4,812±	"	Tuscaloosa; marine, 4,081–4,400± feet
–4,950	No samples	
–5,998	Low. Cret.	

Marine Tuscaloosa included unidentifiable casts of *Corbula* spp., *Pecten?*, and *Tellina?*.

*5. Near Salitpa, Clarke Co., Ala.
Union Producing Co's. M. M. Waite No. 1 Elev. 38 ft. Depth 12,398 ft. AlaGS

– 1,200±	Eocene	Wilcox; Salt Mountain 645–750 feet
– 1,660	"	Midway
– 2,676	Up. Cret.	Selma
– 3,120	"	Eutaw
– 4,630	"	Tuscaloosa; marine at 3,950 feet
– 8,060	Low. Cret.	Glen Rose; non-marine
– 9,460	"	Travis Peak; non-marine
–11,570	Jurassic	Cotton Valley; marine
–11,782	"	Buckner; marine
–12,295	"	Smackover? marine
–12,398	"	Eagle Mills? marine

Log after Miss McGlamery (personal communication) and Imlay (1943).

Florida

Although Florida is also outside the scope of the present report, the writer spent a few days at Tallahassee examining some of the samples in the collections of the State Survey. This study was made possible through the kindness of Herman Gunter, State geologist.

For purposes of correlation with Georgia, logs of wells at Hilliard and Jacksonville, Florida, are given.

*1. Hilliard, Nassau Co., Fla.
St. Marys River Oil Corp., 4 mi. NW. Hilliard Elev. 110 ft. Depth 4,817 ft. FlaGS

0– 40	S.	Pleis.	Satilla
– 90	S.	Pliocene	Caloosahatchee
– 500	S., a little glauc.	Miocene	Hawthorne
– 505	Ss.	Oligocene	
– 860	Ls.	Eocene	Ocala
–1,785	Brown and creamy ls.	"	Claiborne
–1,910?	Ls. and flint	"	Wilcox; Salt Mountain
–2,215	Ls.	"	Wilcox; Ackerman
–2,785?	Ls.	"	Cedar Keys
–2,985	Ls.	Up. Cret.	
–3,440	Chalky ls.	"	Selma
–4,260	Dark greenish gray shale	"	Eutaw
–4,640	Ss., shale, shark teeth	"	Tuscaloosa
–4,795	Hard black shale, a little ss.	Triassic?	
–4,817	Igneous rock	"	

The log is after Cole (1944) who discussed the stratigraphy and described the Foraminifera. The Tuscaloosa was non-fossiliferous except for some shark teeth

(*Odontaspis elegans* Agassiz) identified by J. W. Wells (Cole, 1944, p. 30), found between 4,369 and 4,389 feet.

The shale (4,640–4,795 feet) and the igneous rock (4,795–4,817 feet), referred to the Triassic by Cole, have been the subject of considerable speculation since they were first assigned to the Mississippian (Chattanooga shale) by Campbell (1939). For discussion, see Schuchert (1943) and Cole (1944).

A recent paper by Applin and Applin (1944, p. 1745) gives the following correlation for the Hilliard well.

0– 30	Pleis.	
– 110	Pliocene	
– 500	Miocene	
– 860	Eocene	Ocala
– 945	"	Avon Park } = Claiborne
–1,370	"	Lake City }
–2,215	"	Oldsman = Wilcox
–2,750	"	Cedar Keys = Midway
–3,280	Up. Cret.	Lawson = Navarro
–3,900	"	Beds of Taylor age
–4,254	"	Beds of Austin age
–4,600	"	Tuscaloosa formation
–4,640	Low. Cret.(?)	Red greenish gray, purple mottled clay
–4,800	Paleozoic(?)	

2. JACKSONVILLE, DUVAL CO., FLA.
U. S. Navy; Main Base Housing Project; FSGS W-661 Elev. 15± ft. Depth 987 ft. FlaGS

0– 60	S., cl.	Pleis.	Anastasia
–320	S., sh.	Miocene	
–400	Ls., sh.	"?	
–840	Ls., Bry., forams.	Eocene	Ocala
–987	Ls.	"	

CORRELATION CHART

Table 1 shows the writer's views of the correlation of the main formations of the Coastal Plain between New Jersey and Florida. Though the chart does not include every formation described, it is thought that it covers all formation names mentioned in this paper. For further details on the correlation of the Cenozoic formations of the East Coast see the chart by Cooke, Gardner, and Woodring (1943) and the writer's discussion of it (1945). See also Stephenson *et al.* (1942) for Cretaceous correlation chart.

CROSS SECTIONS

Figures 9–26 are a series of cross sections based on the well logs of the present report. For the purpose of simplification, a few liberties have been taken with these sections. In the first place, in order to keep the depth figures of the diagrams the same as those of the logs in the text, no corrections have been made to refer the depths to sea-level. Though this creates some error, in view of the fact that most of the localities on the Coastal Plain are so slightly above sea-level, it is believed that this error is not significant. Furthermore, no interpolations have been made in the diagrams. The lines of the sections are shown in the accompanying sketch maps.

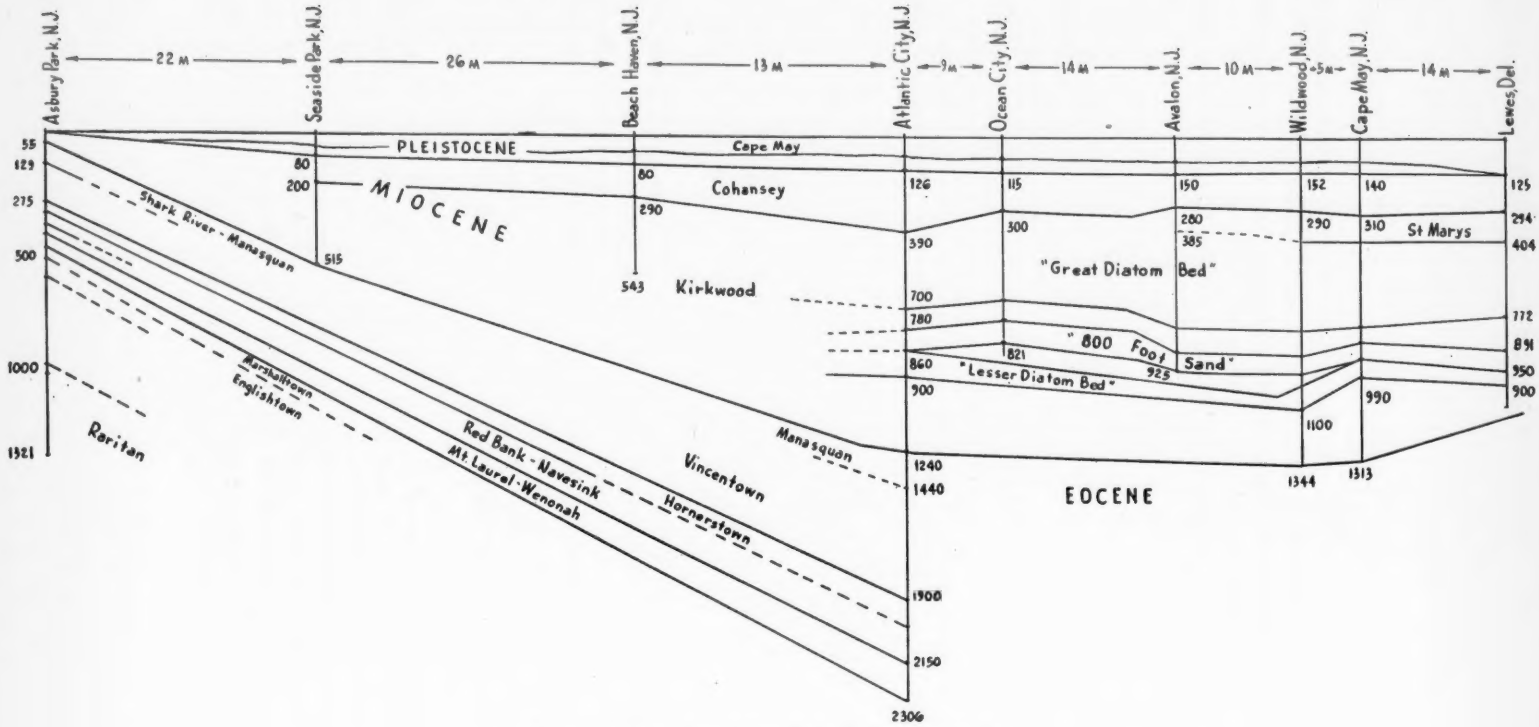

FIG. 9.—Cross section, Asbury Park, N. J., to Lewes, Del.

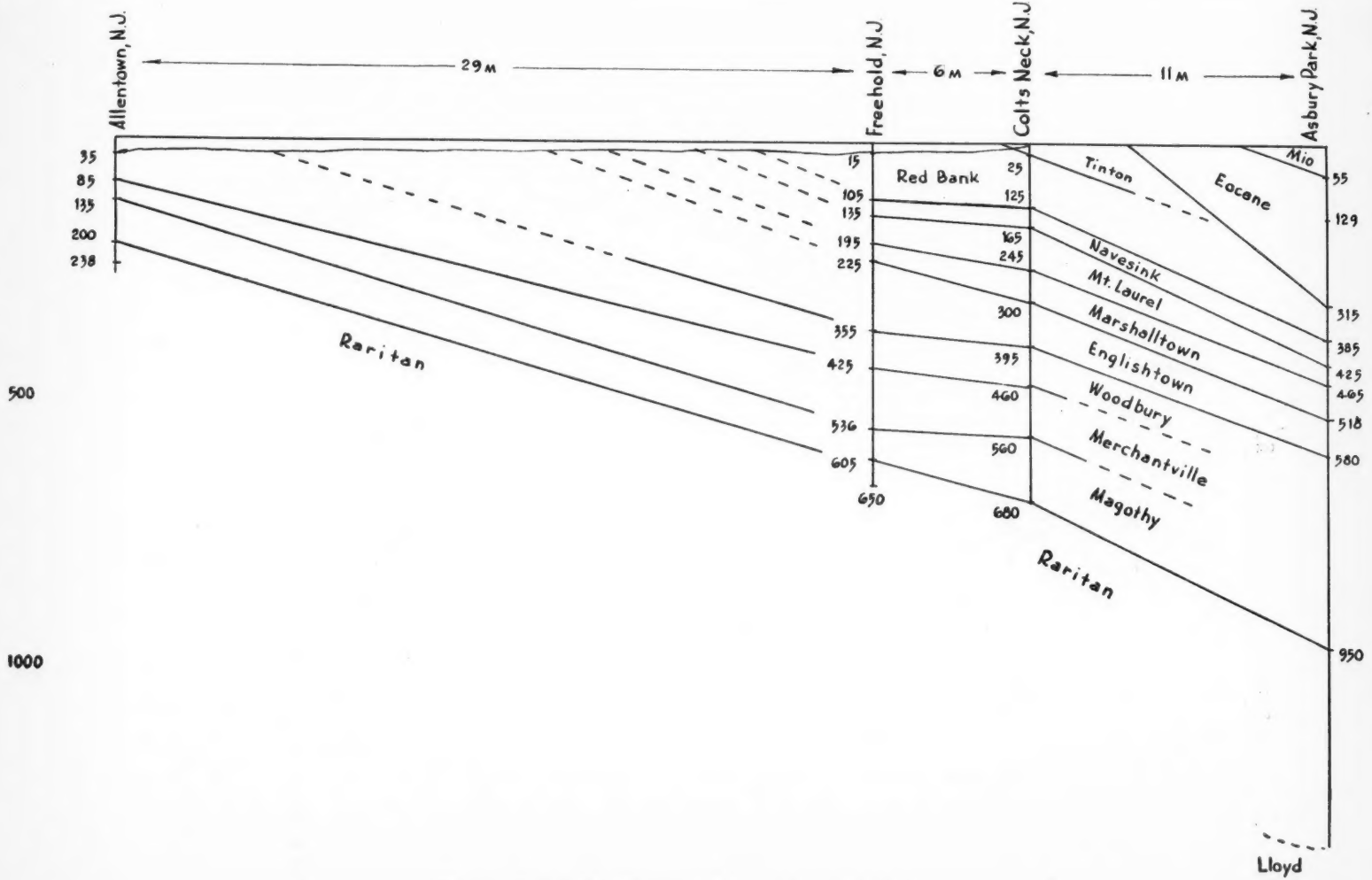

FIG. 10.—Cross section, Allentown, N. J., to Asbury Park, N. J.

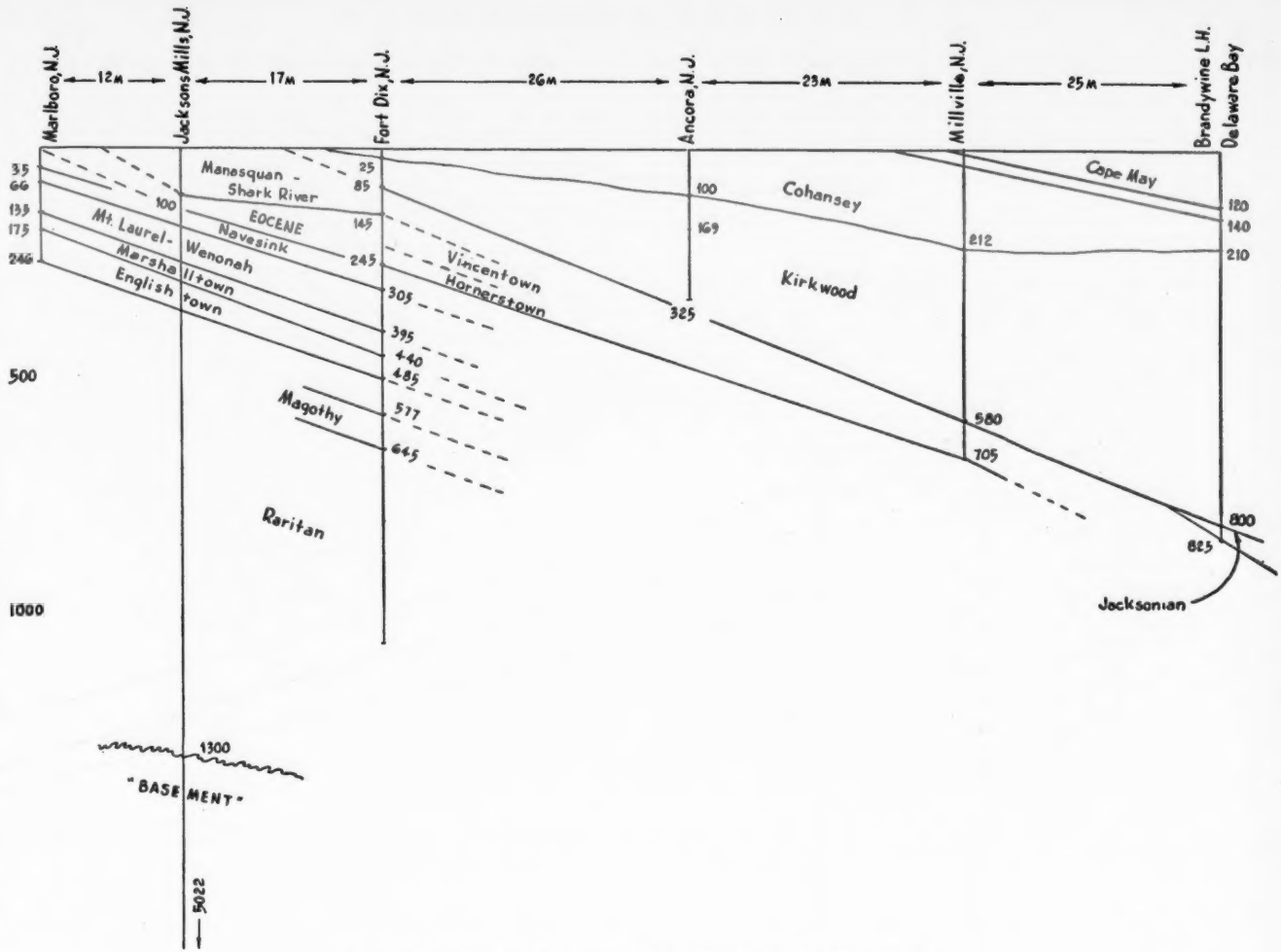

FIG. 11.—Cross section, Marlboro, N. J., to Brandywine Lighthouse, N. J.

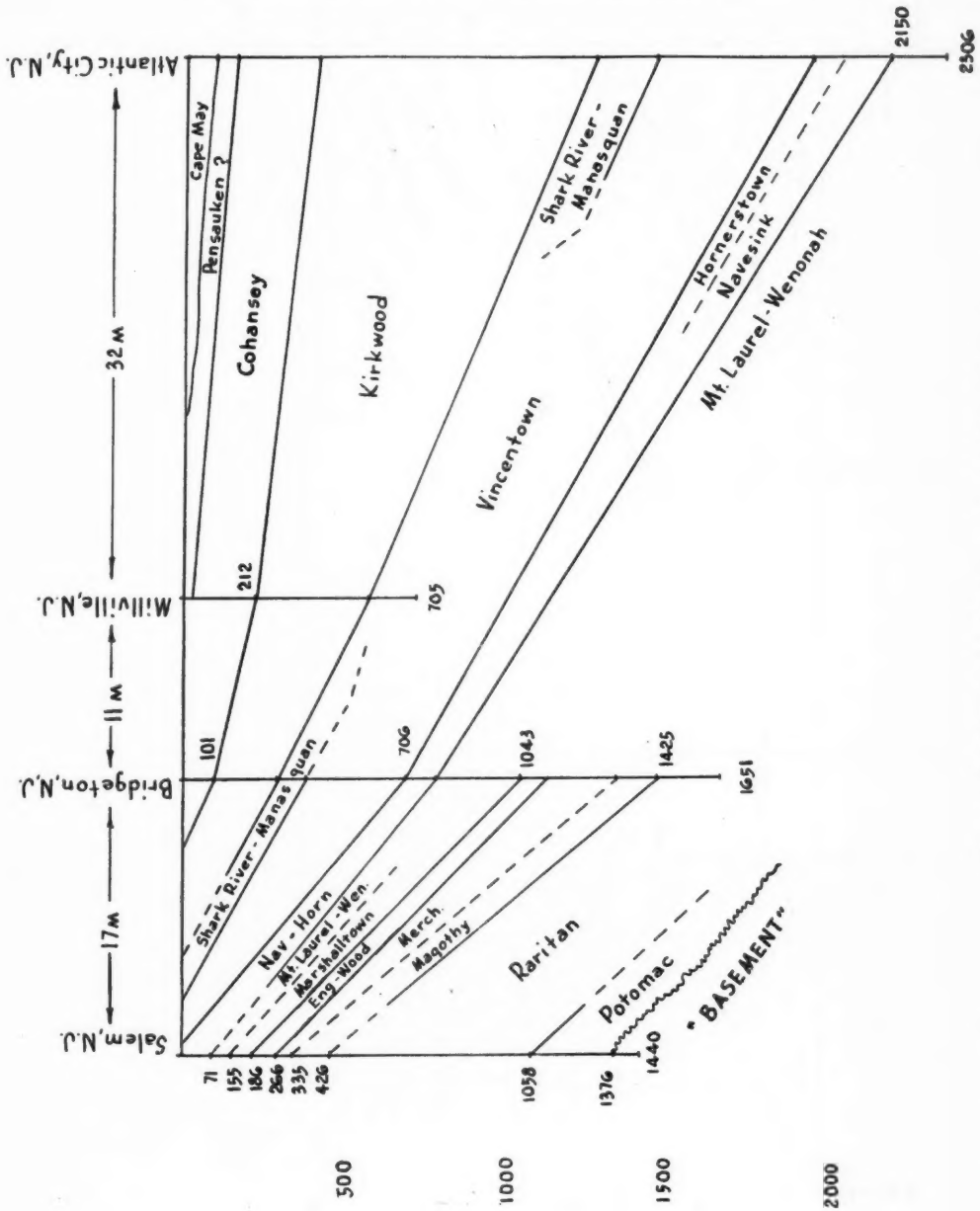

FIG. 12.—Cross section, Salem, N. J., to Atlantic, City, N. J.

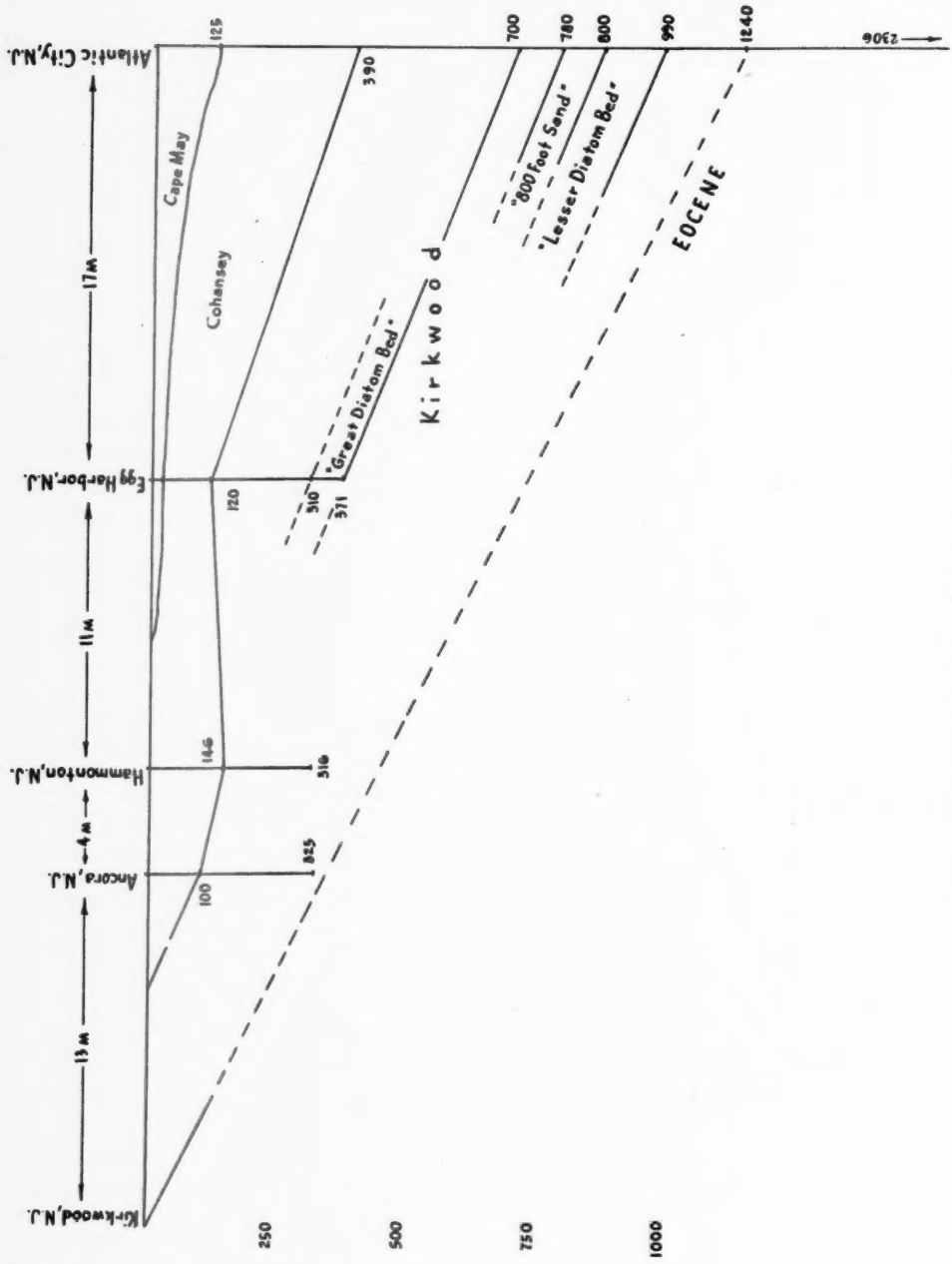

FIG. 13.—Cross section, Kirkwood, N. J., to Atlantic City, N. J.

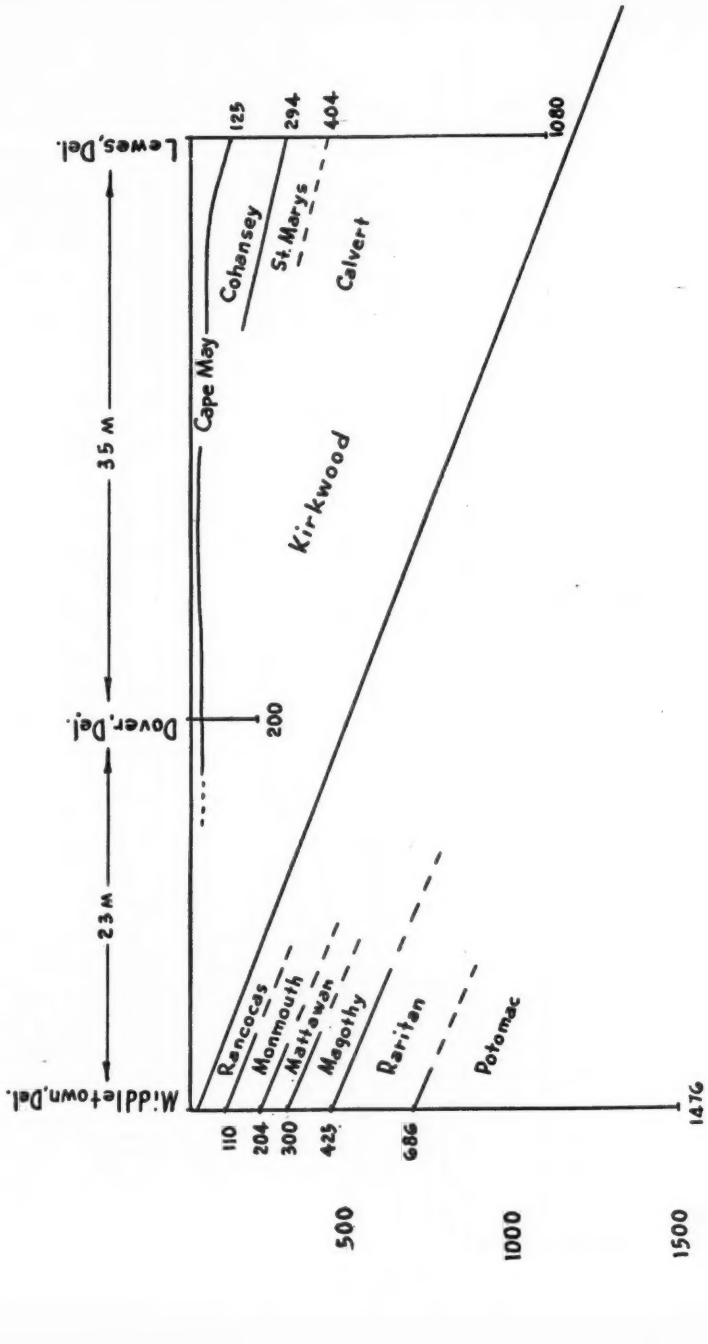

FIG. 14.—Cross section, Middletown, Del., to Lewes, Del.

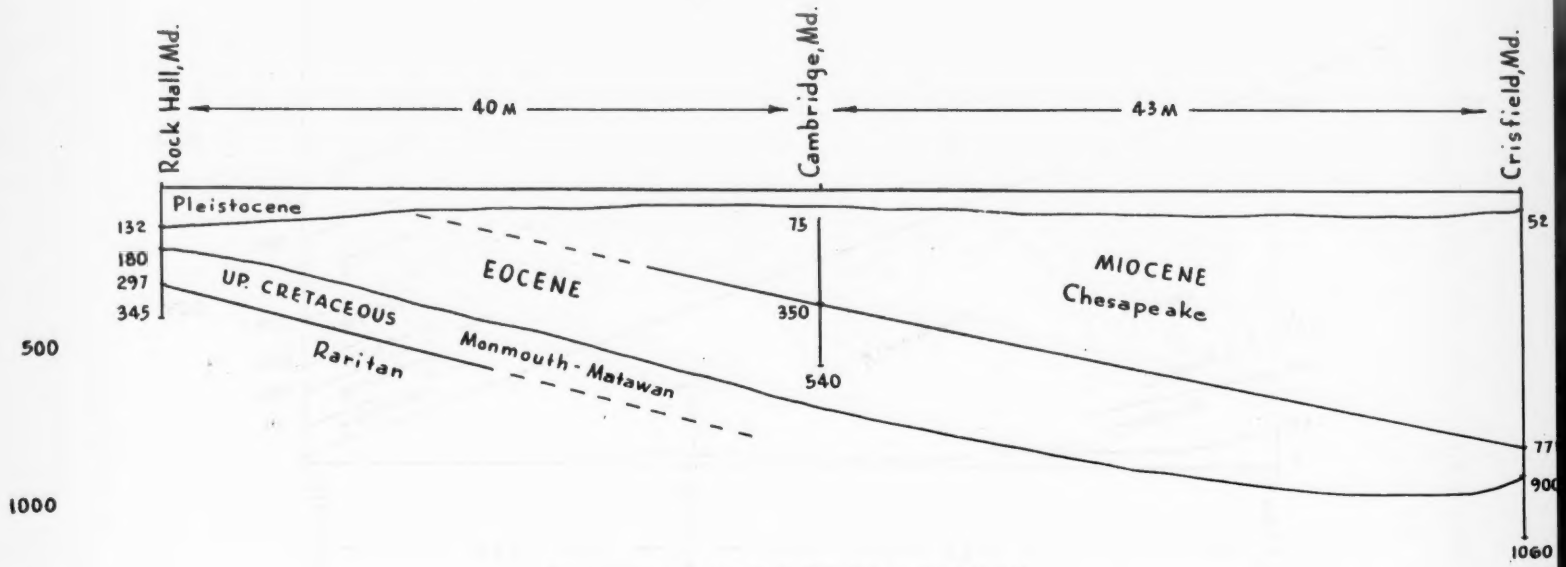

FIG. 15.—Cross section, Rock Hall, Md., to Crisfield, Md.

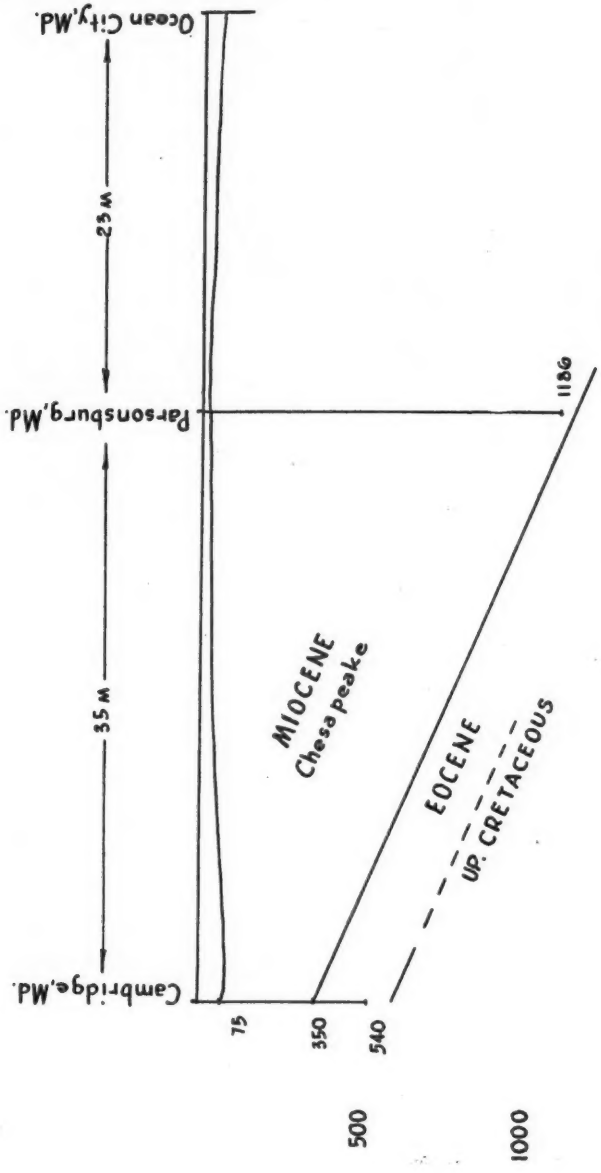

FIG. 16.—Cross section, Cambridge Md., to Ocean City, Md.

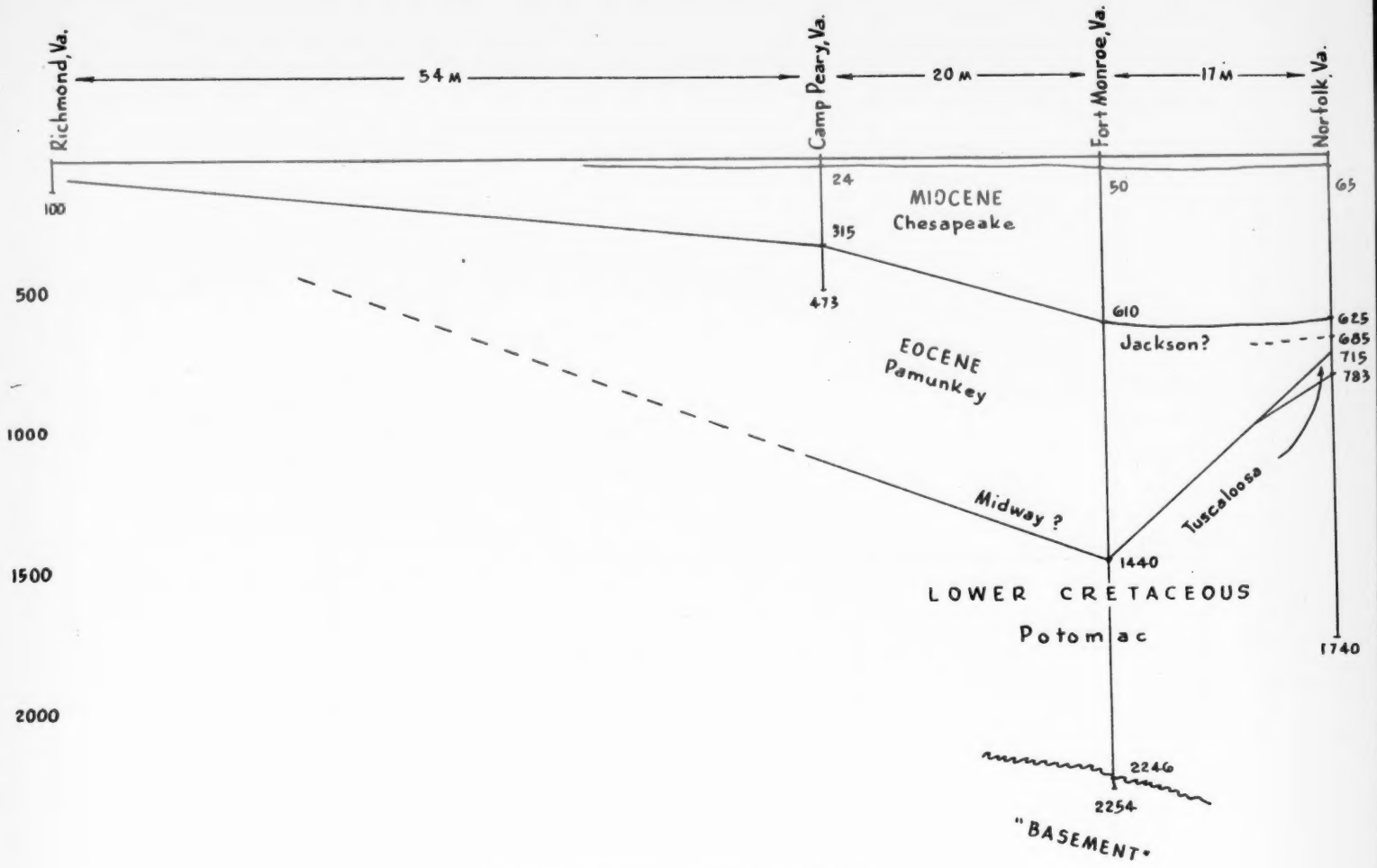

FIG. 17.—Cross section, Richmond, Va., to Norfolk, Va.

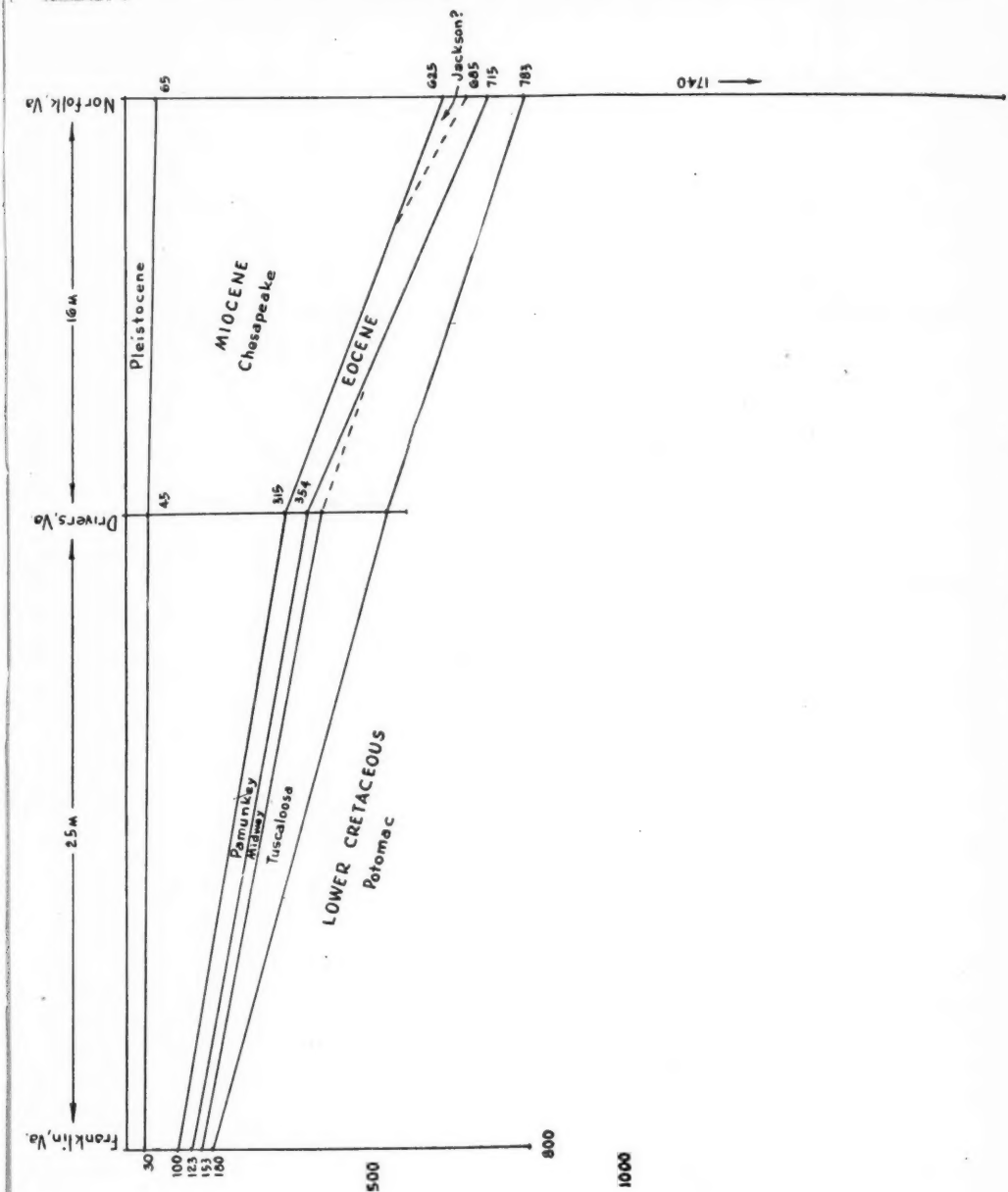

FIG. 17.—Cross section, Richmond, Va., to Norfolk, Va.

FIG. 18.—Cross section, Franklin, Va., to Norfolk, Va.

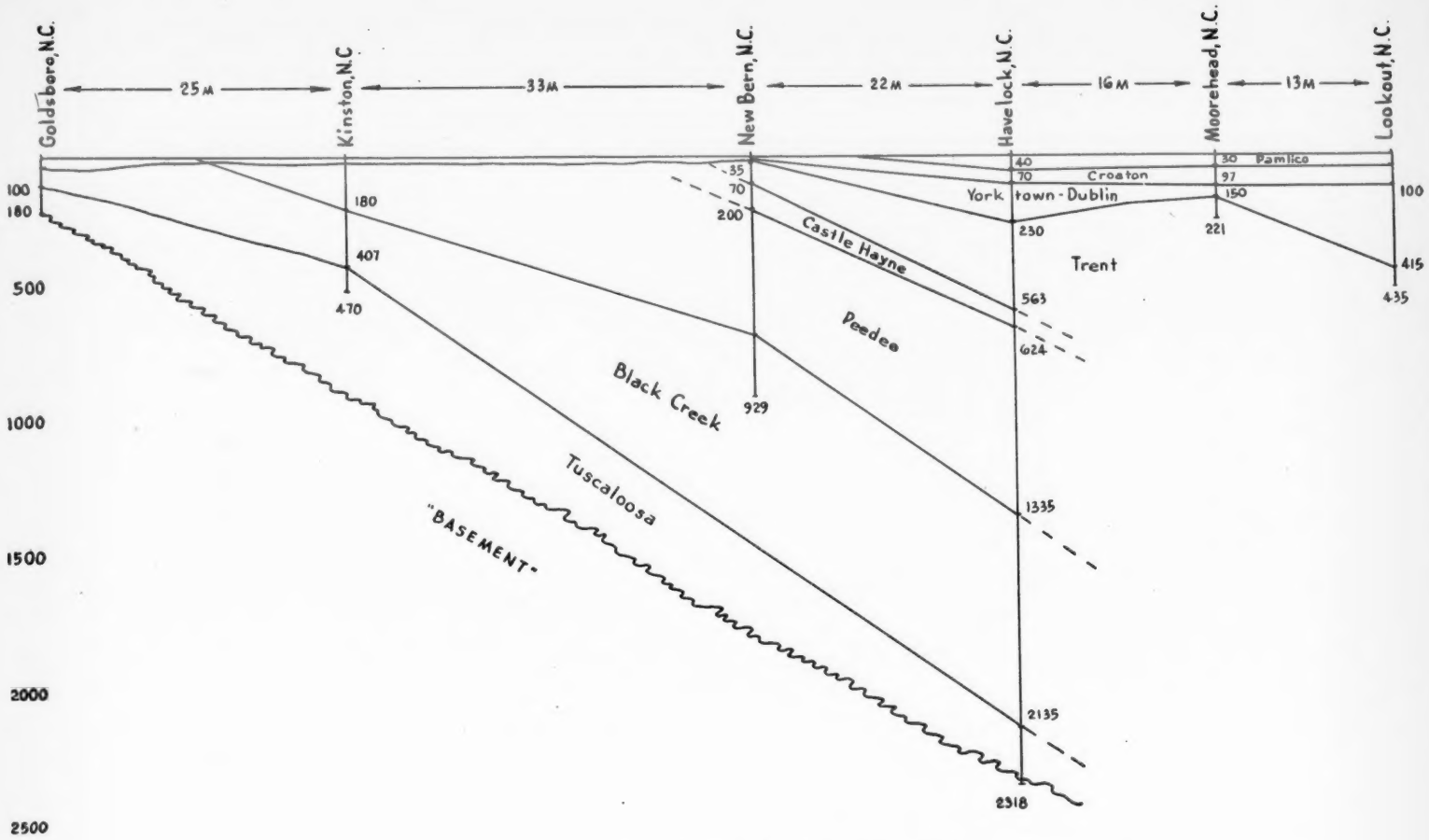

FIG. 19.—Cross section, Goldsboro, N. C., to Cape Lookout, N. C.

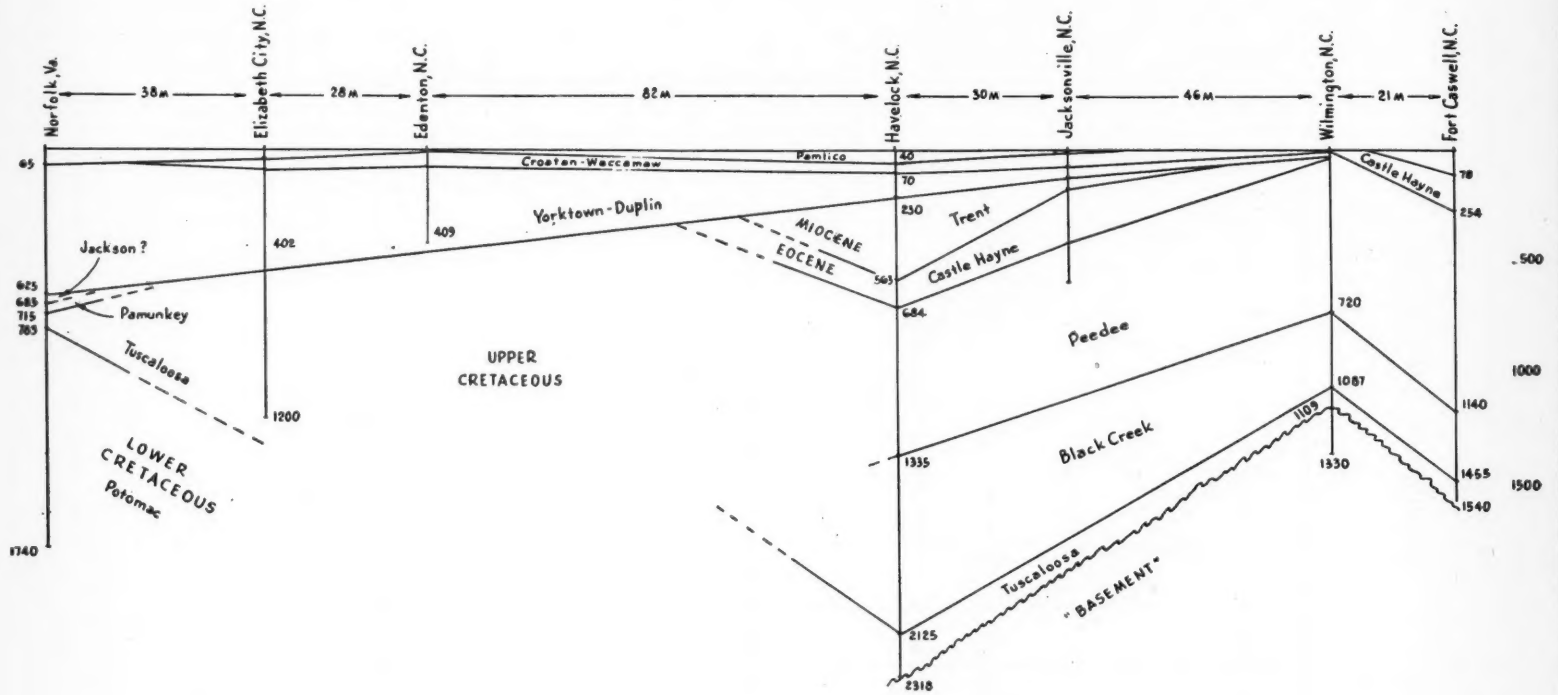

FIG. 20.—Cross section, Norfolk, Va., to Fort Caswell, N. C.

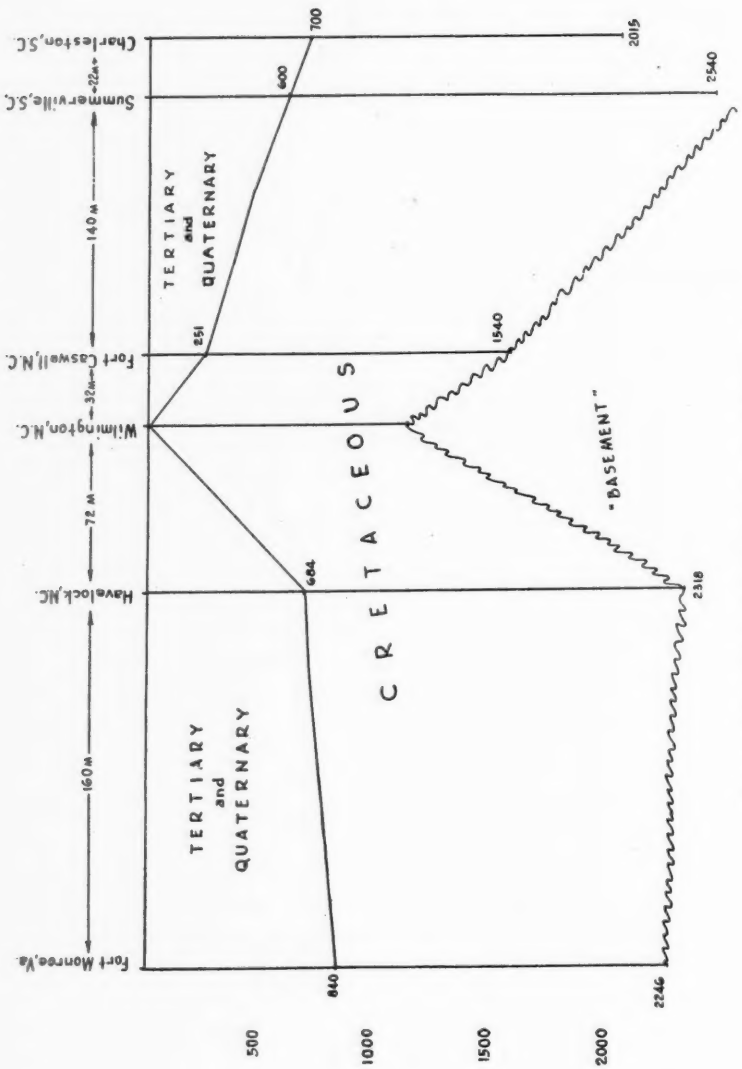

FIG. 21. Cross section, Fort Monroe, Va., to Charleston, S. C.

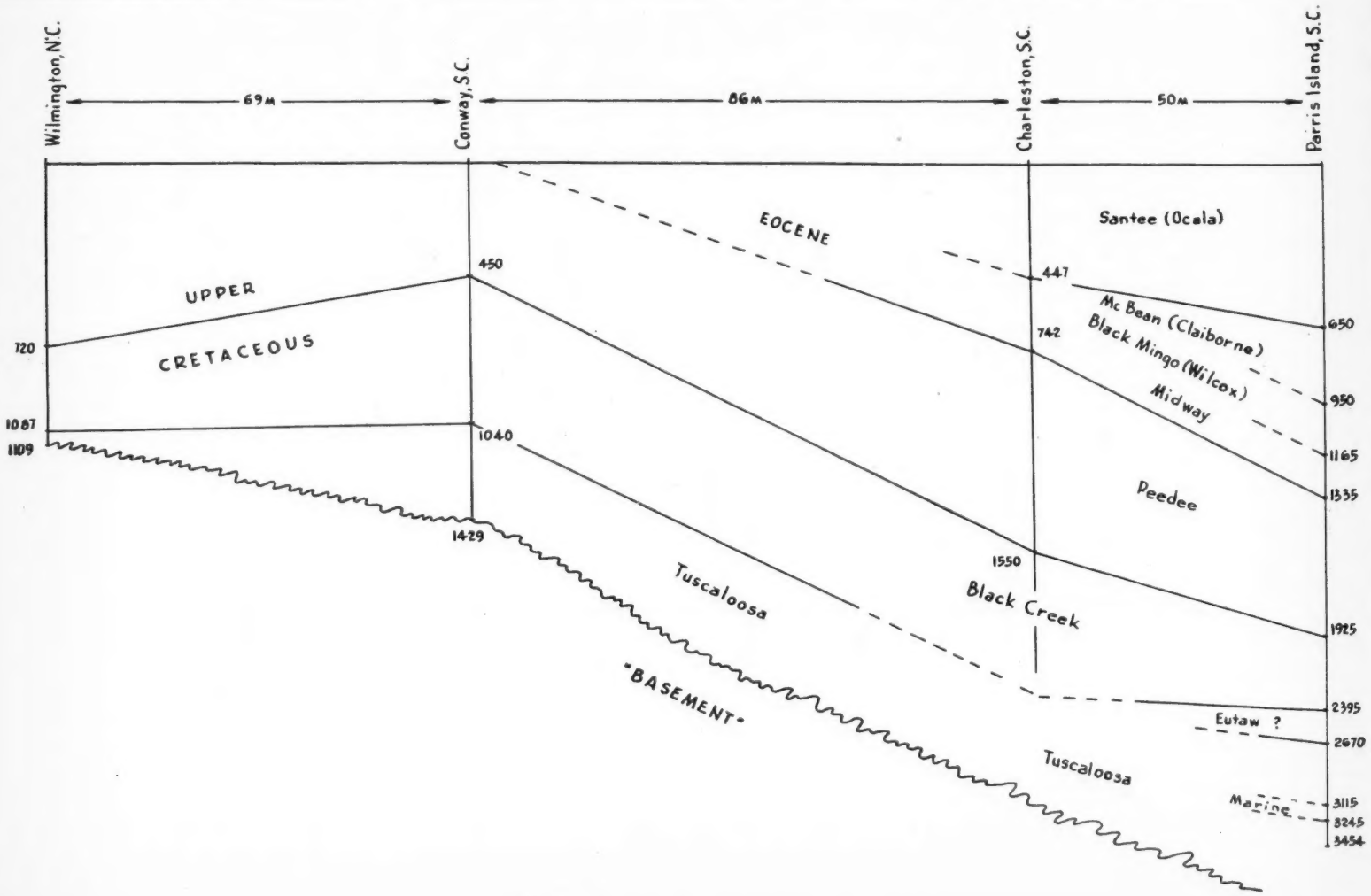

FIG. 22.—Cross section, Wilmington, N. C., to Parris Island, S. C.

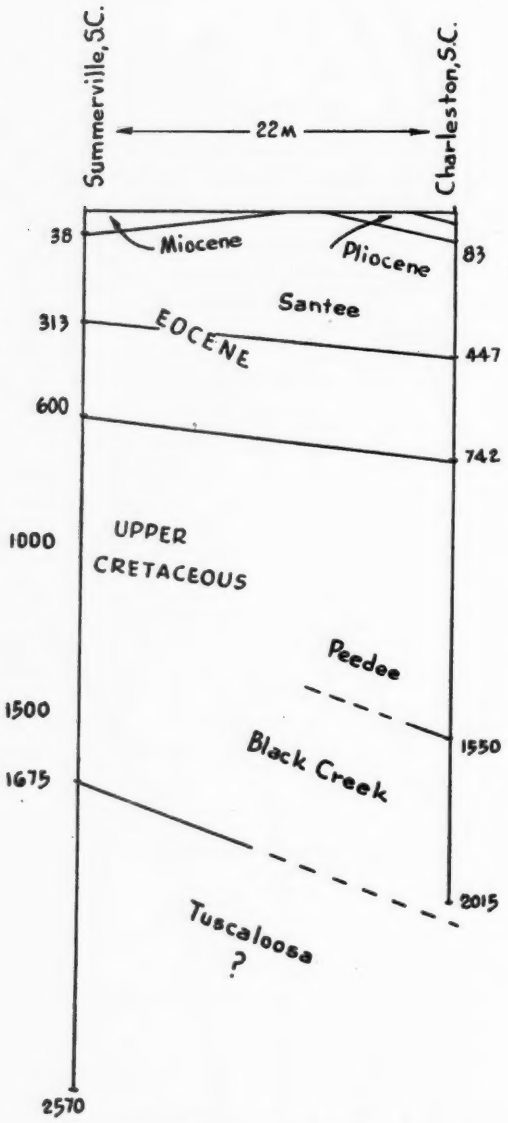

FIG. 23.—Cross section, Summerville, S. C., to Charleston, S. C.

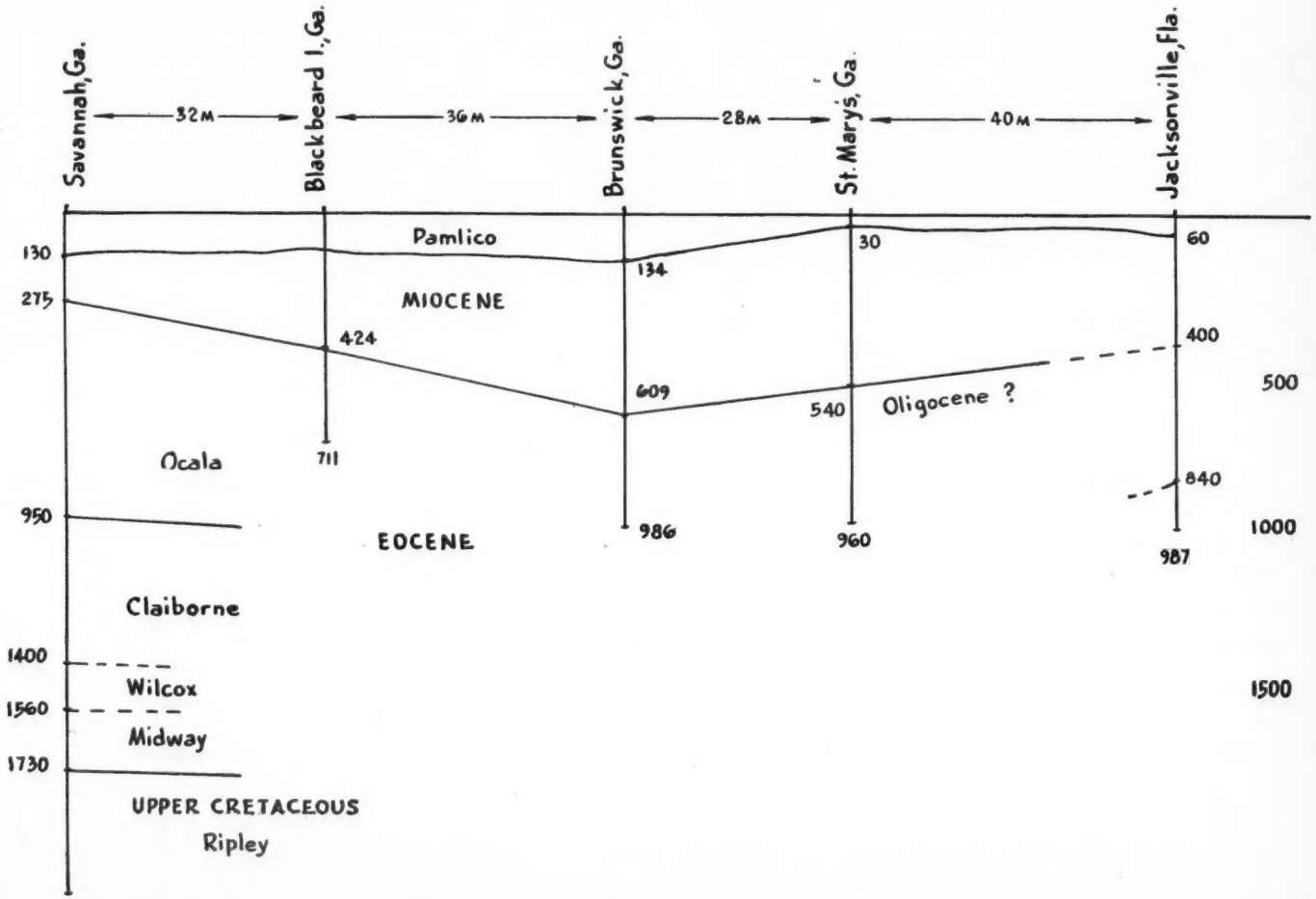

FIG. 24.—Cross section, Savannah, Ga., to Jacksonville, Fla.

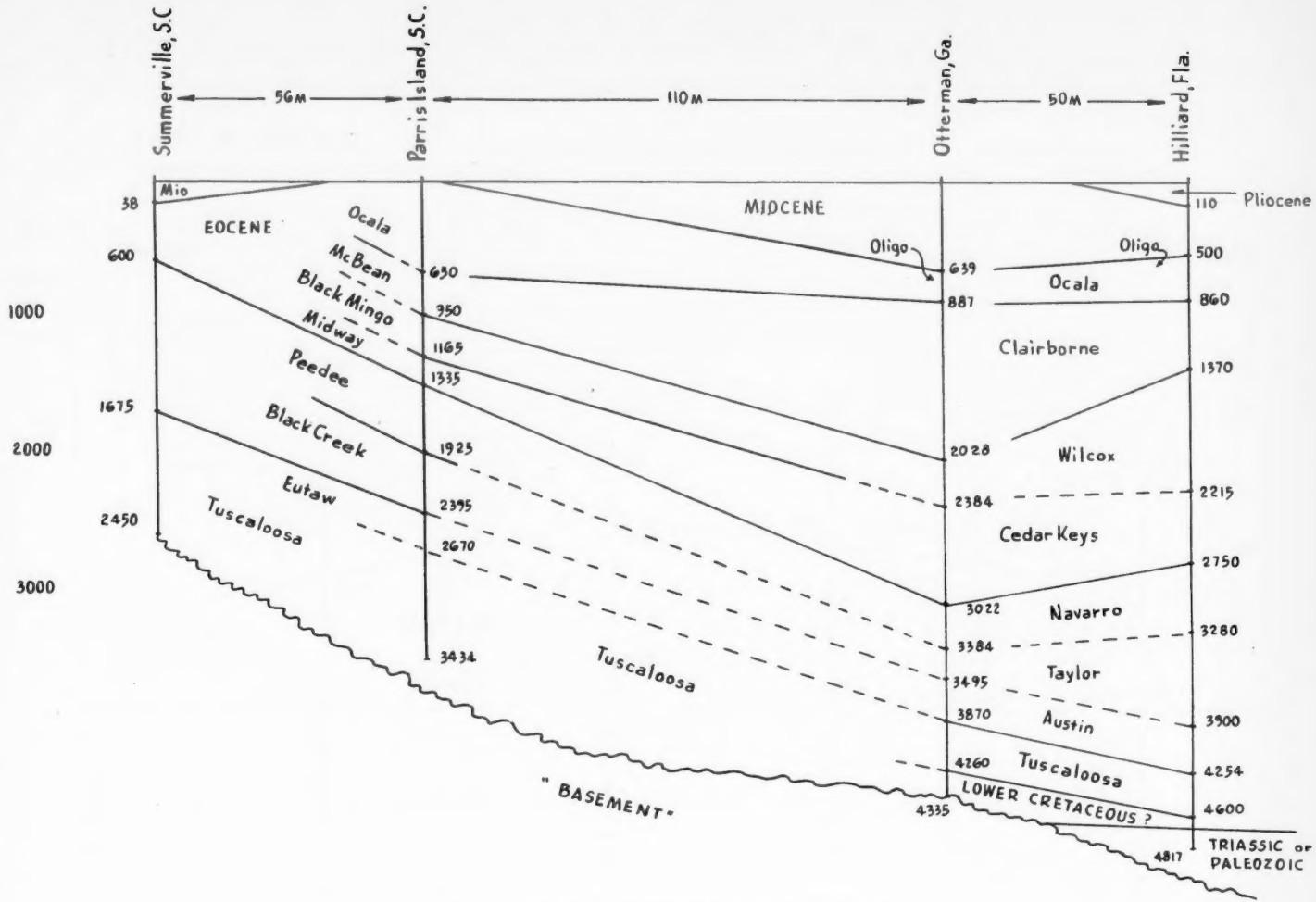

FIG. 25.—Cross section, Summerville, S. C., to Hilliard, Fla.

FIG. 25.—Cross section, Summerville, S. C., to Hilliard, Fla.

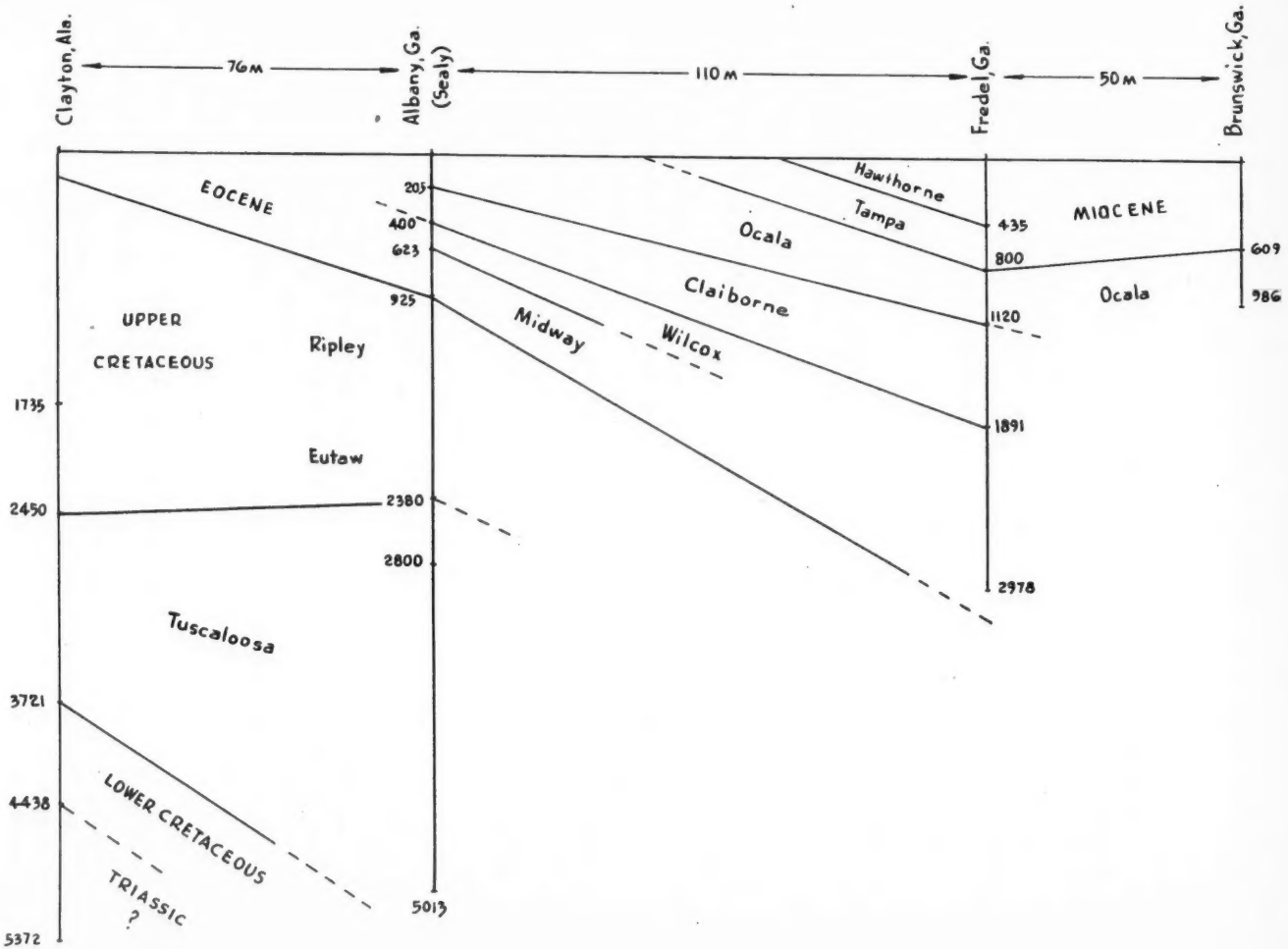

FIG. 26.—Cross section, Clayton, Ala., to Brunswick, Ga.

Summary of Studies of Well Samples

New Jersey

1. Shell fragments and Foraminifera were found in wells at Asbury Park, Fort Dix, and Freehold in the Englishtown sand (Upper Cretaceous). No fossils have hitherto been reported from this formation.

2. Shell fragments were found in wells at Fort Dix and Clementon in the Raritan formation (Upper Cretaceous). A study of fossils from outcrops at Sayreville disclosed a fauna correlated with the Tuscaloosa and Woodbine formations.

3. The presence of Lower Cretaceous non-marine sediments (Potomac group) is indicated in a well at Salem.

4. Jacksonian (Eocene) fossils were found in a well at Brandywine Lighthouse in Delaware Bay, between 800 and 825 feet.

5. An exceptional thickness of the marine Cape May formation (Pleistocene) was noted in wells near Rio Grande. This probably indicates an ancient river channel of the Delaware River.

Delaware

6. Jackson deposits were noted in the well at Bridgeville, between 700 and 850 feet.

7. Midway (Paleocene) Foraminifera were present in the Bridgeville well between 1,120 and 1,330 feet. This is the farthest north that Midway fossils have been reported in print. It should be noted, however, that on the basis of the Foraminifera, Haviland (*ms.*) regarded at least the lower part of the Hornerstown formation of New Jersey as Midway in age.

8. Shell fragments and Foraminifera were found in the Raritan-Tuscaloosa formation between 1,650 and 3,000 feet in the Bridgeville well.

Maryland

9. Thickening of the Miocene is reported in the vicinity of Parsonsburg, to 1,186 feet. At Salisbury, the Miocene-Eocene contact is thought to occur at 1,160 feet.

10. The Salisbury well showed an unusual thickness (3,000± feet) of Lower Cretaceous (Potomac group), although the contact with the Upper Cretaceous (Raritan) is not clear. The Lower Cretaceous is underlain by shales and sandstones which are presumably of Triassic age (Newark). Basement rock (pre-Cambrian?) was struck at 5,529 feet.

Virginia

11. Fossils were found in the Raritan-Tuscaloosa formation in wells at Norfolk, Drivers, and Franklin. A conspicuous pelecypod is *Exogyra* n. sp. closely related to *E. columbella* from the Eagle Ford of Texas.

12. The Midway is thought to be present in subsurface Virginia as indicated by *Spirulaea mcglameri* at Franklin, and Foraminifera identified by Cushman and discussed by Cederstrom (1945, a, b).

13. There is a considerable variation in the thickness of the Eocene on the two sides of James River. This is thought by Cederstrom (1945a) to have been caused by local faulting.

	Extent	*Thickness in Feet*
Fort Monroe	610–1440	830
Newport News	403–1082	679
Norfolk	625– 715	90
Lake Prince	295– 372	77

14. Jackson Foraminifera were recognized in the well at Norfolk, by Cushman (Cederstrom, 1945 b, c).

North Carolina

15. Pamunkey Eocene fossils, especially *Gryphaeostrea vomer*, were noted in the well at Williamston, at the depth of 100–110 feet. Other deposits tentatively referred to the Pamunkey are recorded from Roduco, and Water Lily. The Pamunkey (middle Eocene) apparently pinches out in southern Virginia toward the North Carolina line. However, there are outliers near the Fall Line in North Carolina with fossils presumably of Wilcox or Claiborne age (Richards, 1945).

16. The Castle Hayne (Jackson Eocene) does not occur north of the Neuse River in either surface or subsurface deposits in North Carolina. It may be represented by isolated remnants in the subsurface of Virginia, Maryland, Delaware, and New Jersey.

17. The Tuscaloosa is fossiliferous in the well at Havelock (2,125–2,318 feet). A reëxamination of these samples has disclosed both Foraminifera and macrofossils near the bottom of the well. It is possible that some of the specimens were washed down from the Black Creek or Peedee above, but the presence of *Hamulus* n. sp., similar to one found in the Tuscaloosa in a well near Albany, suggests that at least some of the fossils are in place.

South Carolina

18. The Tuscaloosa is fossiliferous in wells at Conway, and Parris Island. In the well at Parris Island specimens of *Exogyra* n. sp. were noted. This species is known from wells in Virginia and is related to *E. columbella* from the Eagle Ford of Texas.

19. The Triassic (Newark group) has been reported from wells at Florence, and Summerville, but no samples are available for study at this time. Some of these sediments may be Tuscaloosa.

Georgia

20. An exceptional thickness of marine Tuscaloosa is noted in the Sealy No. 1 well near Albany (2,213 feet). Elsewhere it is much thinner. In many places the Tuscaloosa can be divided into three phases, an upper non-marine, a middle marine, and a basal non-marine, but in the Sealy well the marine phase seems to be predominant. A good macrofauna was noted from this deposit.

Alabama

21. Marine Tuscaloosa is present in several wells including: McCorvey No. 1 in Choctaw County, Scotch Lumber Company in Clarke County, and Waite No. 1 in Clarke County. In some Alabama wells the Tuscaloosa can be divided into the three phases as observed in Georgia. It is underlain by the non-marine Lower Cretaceous.

Florida

22. The marine Tuscaloosa is present in the Hilliard well (Cole). It is here underlain by black shale and igneous rock regarded as Triassic by Cole, although this interpretation is questioned by other workers.

Geophysical Studies

A series of four papers has appeared on geophysical investigations of the submerged and emerged Coastal Plain, particularly between New Jersey and Virginia (Ewing, Crary, and Rutherford, 1937; Miller, 1937; Ewing, Woollard, and Vine, 1939, 1940). The New Jersey work has also been summarized by Woollard (1941).

Two traverses were run in New Jersey, one ("Barnegat Bay Section") from Plainsboro to Silverton, and the other ("Cape May Section") from Bridgeport to Avalon. Both used deep well logs as checks. A few of their conclusions may be briefly summarized as follows.

1. In the Barnegat Bay traverse the basement rock dips seaward at approximately 65 feet per mile; in the Cape May traverse it dips between 77 and 84 feet per mile. In both, the dip increases near the coast.

2. The estimated depths of basement rock along the two traverses were as follows.

Barnegat Bay Traverse	*Feet*
Plainsboro	164
Highstown	660
Dis Brows Hill	614
Charleston Springs	1190
Jacksons Mills	1200
Lakewood	1540
Cedar Bridge	1670
Silverton	2220

Cape May Traverse	*Feet*
Bridgeport	193
Prospect	286
Sweedsboro	508
Lincoln	1313
Pittsgrove	1671
Elmer	2143
Norma	2403
Millville	3419
Port Elizabeth	3807
Woodbine	4592
Seaville	Not recorded
Avalon	Not recorded

3. Estimated depths to the V zone (top of Vincentown) and M zone (Magothy-Raritan contact) are also given. These show that the top of the M zone is at about relatively the same elevation in the two profiles, while there is a great thickening of the pre-M zone material to the south. This may be interpreted as a thickening of the Raritan, together with the presence of Lower Cretaceous deposits as shown at Salem, New Jersey, and possibly at Bridgeville, Delaware.

4. Various evidences of local structure are given.

The present writer suggests that it might be better to interpret the M zone as the top of the Magothy rather than the Magothy-Raritan contact. There is a much more definite break between the Merchantville and Magothy formations in New Jersey than between the Magothy and the Raritan. Furthermore, there is commonly a zone at the base of the Merchantville which contains may ironstone crusts which might give the effect of a consolidated bed in geophysical tests. It is practically impossible to separate the Magothy and Raritan on the basis of lithology, especially in southern New Jersey and Delaware. It therefore seems unlikely that the seismic waves would reflect this contact, whereas they might well reflect the Magothy-Merchantville (or Matawan) contact.

It is believed that the recent geophysical exploratory work by several of the major oil companies in New Jersey, Delaware, and Maryland will be very illuminating, when and if released.

The geological significance of the Cape Henry traverse was summarized by Miller (1937). A few of his conclusions are the following.

1. Well records show that the basement rock dips at a rate of about 30 feet per mile in eastern Virginia, but in North Carolina, the dip is only 10 feet per mile. The geophysical results show a slope of about 30 feet per mile from the Fall Line near Petersburg, Virginia, to a point about 20 miles east of Cape Henry, Virginia. Beyond this the slope increases, so that at a point approximately 60 miles at sea, off Cape Henry, the basement may be 12,000 feet deep.

2. The geophysical data suggest that there are two main zones in the sediments overlying the crystallines, particularly east of the present shore line. The upper zone is thought to include Cretaceous and younger, and the lower zone may include some Jurassic and Triassic and may well be marine farther east. The two zones were also recognized in the wells at Fort Monroe, Virginia, and Matthews, Virginia, but an examination of the logs gives no indication of any sediments earlier than Lower Cretaceous. (The present writer has found no indications of marine sediments in the lower part of these two wells.)

In comparing the Virginia and New Jersey traverses it was later pointed out (Ewing, Woollard, and Vine, 1939, p. 285) that the seismic break in Virginia might well be the M zone of the New Jersey traverses. It is believed by the present writer that this represents the Magothy-Matawan contact rather than the Raritan-Magothy contact as indicated by earlier workers. The Raritan-Magothy contact is practically impossible to recognize lithologically or faunally, but the Magothy-Matawan contact is marked by a definite break. This contact might well occur at approximately the depths indicated by the seismic studies. The lower part of the sediments seaward of Cape Henry may be pre-Cretaceous and marine.

Configuration of Basement Rock

Figure 27 is a diagrammatic representation of the configuration of the basement rock along the Coastal Plain between New Jersey and South Carolina. It is

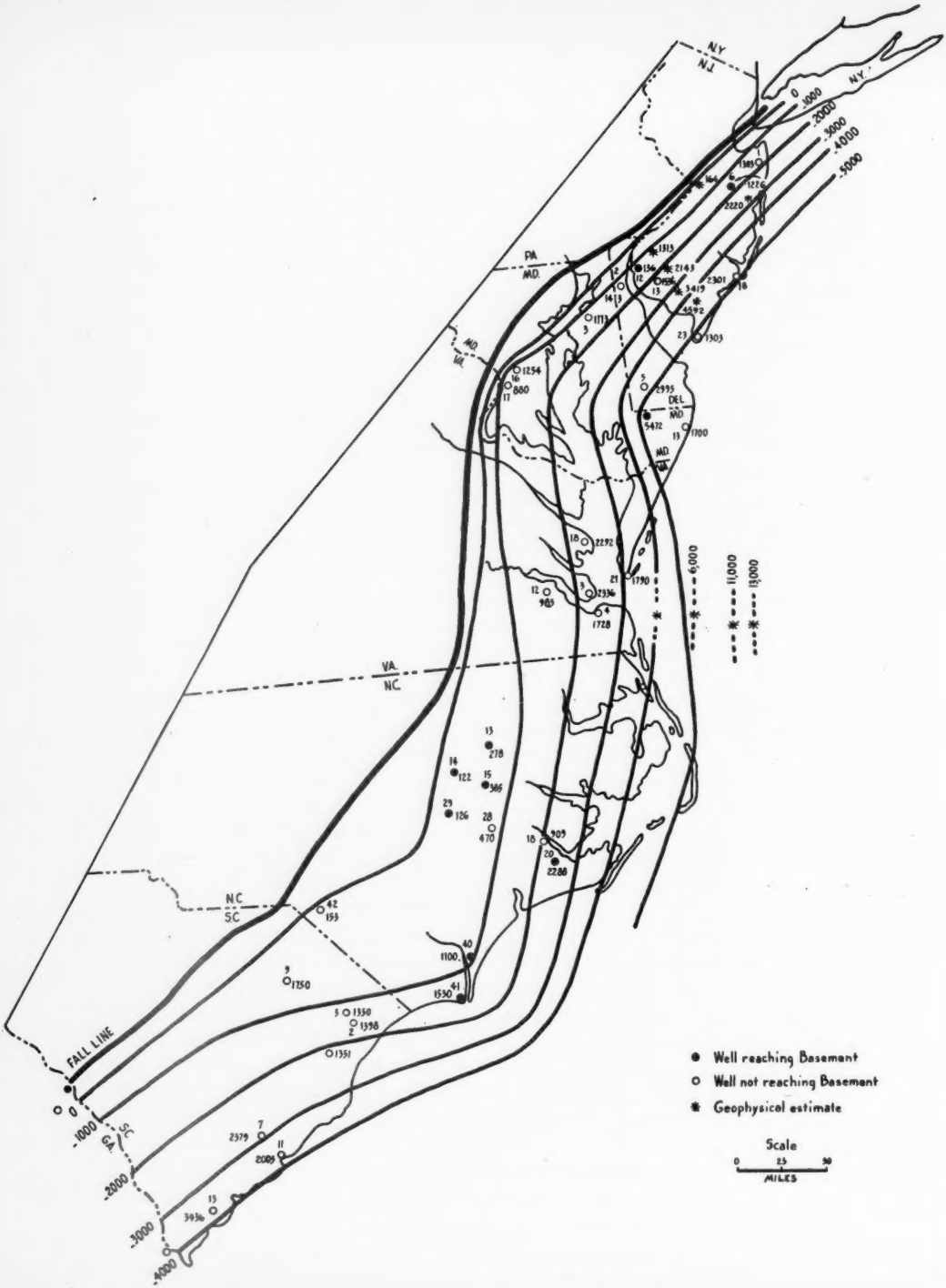

FIG. 27.—Map showing basement contours, New Jersey to South Carolina.

based on well logs of the present report and available geophysical data. No attempt is made to identify the basement rock, although it is probable that most of it is pre-Cambrian. Obviously a map such as this is incomplete and inaccurate and will undoubtedly be altered when more deep well logs are available. However, it represents our present knowledge of the structure of this area. A few features are of special interest.

1. A conspicuous "high" is noted in the vicinity of Cape Fear, North Carolina. This has been recognized for a long time and is known as the Great Carolina ridge.

2. Some workers believe that there is a fault in the vicinity of Summerville, South Carolina. If the shaly material between 1,580 and 2,470 feet is Triassic, as believed by Cooke, it may well be a down-faulted area. On the other hand, Mansfield regarded the material as Tuscaloosa (Upper Cretaceous) which would normally be expected in that area. Since no samples from the well are now available, the matter can not be settled at this time.

3. The well at Florence, South Carolina, is very difficult to correlate with near-by logs, especially those near Conway, South Carolina. At Florence, the Triassic was reported from 608 to 1,335 feet, with the "basement" presumably still deeper. Near Conway, South Carolina, the basement (pre-Cambrian?) was reported at 1,375 and 1,429 feet (1,350 and 1,398 below sea-level). The Florence record is based only on a driller's log, and may be subject to error. On the other hand, it may represent a local down-faulted area.

4. An exceptionally flat area is noted in North Carolina between the 0– and 1,000-foot contour.

5. Cederstrom (1945a) has recently expressed the view that the region in the vicinity of Norfolk, Virginia, is similar to that at Cape Fear, North Carolina, and represents a 300 to 600-foot fault in the basement rock. There is a definite variation in the thickness of the Eocene on the two sides of James River. This is believed to represent a fault.

6. A "low" extends inland from the Maryland coast through Salisbury, Maryland, to the outskirts of Washington, D. C. Because of the great thickness of the non-marine Lower Cretaceous in the Salisbury well, it is possible that this may represent an ancient estuary, possibly the ancestor of Chesapeake Bay, or the Potomac River; on the other hand, this may also be a fault.

7. It is possible that this "low" extends north to Delaware Bay. This is suggested by the geophysical tests in southern New Jersey which indicate that the basement is at −4,592 feet at Woodbine, and somewhat deeper at Seaville, and Avalon.

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* For convenience it is assumed that these reports appeared during the year for which they were written. Thus Woolman (1890) means the report for 1890.

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STRATIGRAPHIC RELATIONS OF UPPER CRETACEOUS IN GREAT VALLEY, CALIFORNIA[1]

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ABSTRACT

The paper deals with the Upper Cretaceous beds of the Sacramento and San Joaquin valleys between the latitude of Redding on the north and the latitude of Lost Hills on the south. On the basis of foraminiferal study of a number of surface sections and of core samples obtained from 128 wells the Upper Cretaceous strata of the Great Valley have been divided into twelve zones, four of which are assumed to be represented each by two different ecological facies. The zones are grouped into seven stages. Foraminiferal and lithologic characteristics of the zones, their areal distribution, and stratigraphic relations are discussed and illustrated by cross sections and a diagrammatic map. Another map shows contours of the Cretaceous surface. Eight small-scale maps elucidate paleogeography of the zones and their ecological variations.

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of the Independent Exploration Company; Harry Campbell of the Jergins Oil Company; Glen B. Gariepy of the Ohio Oil Company; Norman L. Thomas of the Pure Oil Company; H. W. Hoots of the Richfield Oil Corporation; Vincent W. Vandiver of the Seaboard Oil Company; E. F. Davis and M. G. Edwards of the Shell Oil Company; W. S. W. Kew of the Standard Oil Company; John D. Hale, A. R. May, and R. B. Hutcheson of the Superior Oil Company; Hampton Smith of The Texas Company; Earl B. Noble and Louis N. Waterfall of the Union Oil Company, and R. W. Clark of the Western Gulf Oil Company. To all of them the writer wishes to express his gratitude.

INTRODUCTION

The sedimentary rocks discused in this paper are those shown as Upper Cretaceous on the Geological Map of California compiled by Olaf P. Jenkins and published by the California Division of Mines in 1938. They correspond with the Chico formation or Chico group which, as defined by W. B. Gabb,[3] includes all the strata underlying the Martinez formation (lower Eocene) and overlying the Shasta group (Lower Cretaceous). The same sediments were later classified by F. M. Anderson as the Chico series.[4]

PREVIOUS WORK

The first attempts at foraminiferal zoning of the Upper Cretaceous of the Great Valley were reported by the writer to the Pacific Section of the Society of Economic Paleontologists and Mineralogists in April, 1936, and to the twenty-second annual meeting of the American Association of Petroleum Geologists in March, 1937.[5] These reports were based on micropaleontological study of very limited material (eight wells and one surface section). Consequently, the stratigraphical relations of some of the recognized foraminiferal zones remained indeterminate, and great difficulty was experienced in correlation of wells in the Sacramento Valley with those in the southern part of the basin. Also, our knowledge of the field divisions of the Cretaceous column was limited at that time to the discussion of the outcrops along the west side of the San Joaquin Valley, north of Coalinga,[6] and to the report by Taff on the geology of the area north of Mount Diablo.[7]

[3] W. B. Gabb, "Paleontology," Vol. 2, *California Geol. Survey* (1869), p. xiv.

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[5] Abstract of the latter paper was published in the program of the meeting on page 61.

[6] Robert Anderson and R. W. Pack, "Geology and Oil Resources of the West Border of the San Joaquin Valley North of Coalinga, California," *U. S. Geol. Survey Bull. 603* (1915).

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Since 1938 the Cretaceous beds of California, after a long period of neglect, have attracted a marked increase of attention which has resulted in a series of published papers and talks delivered before various scientific societies and recorded in abstracts.

Stratigraphy of the Upper Cretaceous in the Sacramento Valley has been discussed by J. M. Kirby,[8] by W. P. Popenoe,[9] and by J. A. Taff jointly with G. D. Hanna and C. M. Cross.[10]

New divisions of the Moreno and Panoche formations have been proposed by F. M. Anderson,[11] by Allen Bennison,[12] by Max B. Payne,[13] and by J. Q. Anderson.[14]

In addition to the fossils listed in some of the papers just mentioned, new organic remains have been reported by Samuel P. Wells,[15] Chester Stock,[16] Arthur S. Campbell and Bruce L. Clark,[17] Arthur W. Nauss,[18] Charles L. Camp,[19] J. Wyatt Durham,[20] Hubert G. Schenck,[21] and C. C. Church.[22]

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[13] Max B. Payne, "Moreno Shale, Panoche Hills, Fresno County, California" (abstract), *Program*, Geol. Soc. America, Cordilleran Section (1941), p. 19.

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[15] Samuel P. Welles, "Plesiosaur from Upper Cretaceous of San Joaquin Valley," *Program and Abstracts*, summer meeting, Geol. Soc. America, at Univ. of California, August 8–10, 1939, p. 32.

[16] Chester Stock, "Duckbill Dinosaur from the Moreno Cretaceous, California" (abstract), *Program*, Geol. Soc. America, Cordilleran Section (1941), p. 22.
———, "The Cretaceous Vertebrates Record of California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 11 (1941), p. 2094.

[17] Bruce L. Clark, "Radiolarian Fauna from the Upper Cretaceous of the Tesla Quadrangle, Middle California," *Bull. Geol. Soc. America*, Vol. 53, No. 2 (1942), p. 1835. Also *Geol. Soc. America Spec. Paper 57* (1944).

[18] Arthur W. Nauss, "Upper Cretaceous Ammonites of the Genus Baculites -N California" (abstract), *Bull. Geol. Soc. America*, Vol. 53, No. 12, Pt. 2 (December 1, 1942), p. 1836.

[19] Charles L. Camp, "California Mesosaurs," *Memoirs Univ. California*, Vol. 13, No. 1 (1942), pp. 1–68.

[20] J. Wyatt Durham, "Pacific Coast Cretaceous and Tertiary Corals," *Jour. Paleon.*, Vol. 17, No. 2 (1943), pp. 196–202.

[21] Hubert G. Schenck, "*Acila princeps*, a New Upper Cretaceous Pelecypod from California Cretaceous," *ibid.*, Vol. 17, No. 1 (1943), pp. 60–68.

[22] C. C. Church, "Description of Foraminifera," *California Div. Mines Bull. 118*, Pt. 2 (1941), p. 181.

Papers dealing with the Upper Cretaceous outside of the Great Valley, but important for interpretation of the Cretaceous stratigraphy discussed in the present paper, have been published by W. P. Popenoe[23] and by N. L. Taliaferro.[24]

During the same period very valuable subsurface material has been obtained from wells drilled throughout the Great Valley down to and into the Upper Cretaceous beds, and well exposed surface sections have been systematically sampled by geologists of several oil companies and by individual workers.

MATERIAL STUDIED AND PRINCIPAL RESULTS

The present discussion is based on a micropaleontological study of core samples from 128 wells and of outcrop samples from 18 surface sections and 4 other localities.

The study of the voluminous additional material has resulted in considerable changes of the writer's earlier conclusions.

First, it has been found that, with a few exceptions, the species which were considered as diagnostic of certain zones can be used as guiding fossils only in combination with some other species. In view of this, it now appears inadequate to designate the foraminiferal zones by the name of a single species, as it was previously proposed by the writer. Consequently, the zones are indicated merely by capital letters.

Also a perceptible lateral variation has been discovered in the foraminiferal content of some of the zones. The stratigraphical equivalence of the beds containing different foraminiferal assemblages has been established by: (1) similar relationship of these beds to overlying and underlying zones; (2) presence of several species remaining common in generally dissimilar faunules; (3) gradual change in the microfaunal content of a stratigraphic unit that can be observed step by step from wells along the west side of the San Joaquin Valley toward those along the east side of the same valley and also from the area south of the Mt. Diablo Meridian Base toward the Sacramento Valley; and (4) lithologic variation from shale to silt, as in the upper part of the Cretaceous column on the west side of the San Joaquin Valley south and north of the Pacheco Pass. Four zones assumed to be represented by ecologically different facies are designated in this paper as A-2 and A′-2 C and C′, E and E′, and F-1 and F′-1.

A comparative study of foraminiferal content, stratigraphic relationship and areal distribution of the zones has revealed that the zones can be grouped into seven units each deserving the rank of stage. Two of these stages are named by

[23] W. P. Popenoe, "Upper Cretaceous Formations and Faunas of Southern Californa," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 2 (1942), pp. 162–87.

———, "Cretaceous Formations of the Northern Santa Ana Mountains," *California Div. Mines Bull. 118*, Pt. 3 (1943), pp. 364–66.

[24] N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges of California," *California Div. Mines Bull. 118*, Pt. 2 (1941), pp. 119–63.

———, "Cretaceous and Paleocene of Santa Lucia Range," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 4 (1944), pp. 449–521.

the writer after the surface sections from which a fairly good sequence of the foraminiferal faunules typical of these stages have been obtained. The foraminiferal material characteristic of the other five stages has been found either only in wells or in the surface section the names of which are preëmpted for some of the Upper Cretaceous formations. The names proposed for these five stages refer to the districts or areas in which the corresponding wells or surface sections are located.

For reference, Table I shows the divisions proposed by the writer, their tentative correlation with the Texas Cretaceous groups, and the stratigraphical position of the known commercial gas and oil zones in the California Cretaceous.

TABLE I

Names Proposed in This Paper			*Commercial Gas and Oil Zones*	*Texas Cretaceous Groups*
Zones	*Ecological Variants*	*Stages*		
Pre-Martinez Paleocene				
A-1		Upper Cheneyan	Gas in Afton field	
A-2	A′-2	Lower Cheneyan		
	Upper Cretaceous			
B		Upper Ciervian		
C	C′	Lower Ciervian		
D-1		Upper Ingramian	Gas in Vernalis and Cheney Ranch fields	
D-2		Lower Ingramian	Gas in Tracy field	Navarro group
E	E′	Tracian	Gas in Willard Ranch, Ord Bend, and Colusa fields	
F-1	F′-1	Upper Weldonian	Gas in Marysville-Buttes, Chico and Chowcilla fields	Taylor
F-2		Lower Weldonian		
G-1		Upper Cachenian	Oil in Oil City field	Eagle Ford
G-2		Lower Cachenian		
H		Delevanian		Woodbine

EXPLANATION OF ILLUSTRATIONS

The map (Fig. 1) has been prepared to show the wells and outcrops from which the writer has secured samples of the Upper Cretaceous beds (because of small scale some of the dots on the map indicate more than one well). In addition, mostly around the town of Rio Vista, there are also plotted nine wells which, though drilled to post-Cretaceous strata are important for defining the contours of the Cretaceous surface. Areas of surface occurrence of the Upper Cretaceous, Lower Cretaceous, Knoxville, and Franciscan sediments, as well as of metamorphic and granitic rocks of the Sierra Nevada, have been copied from the geologic map compiled by Jenkins.

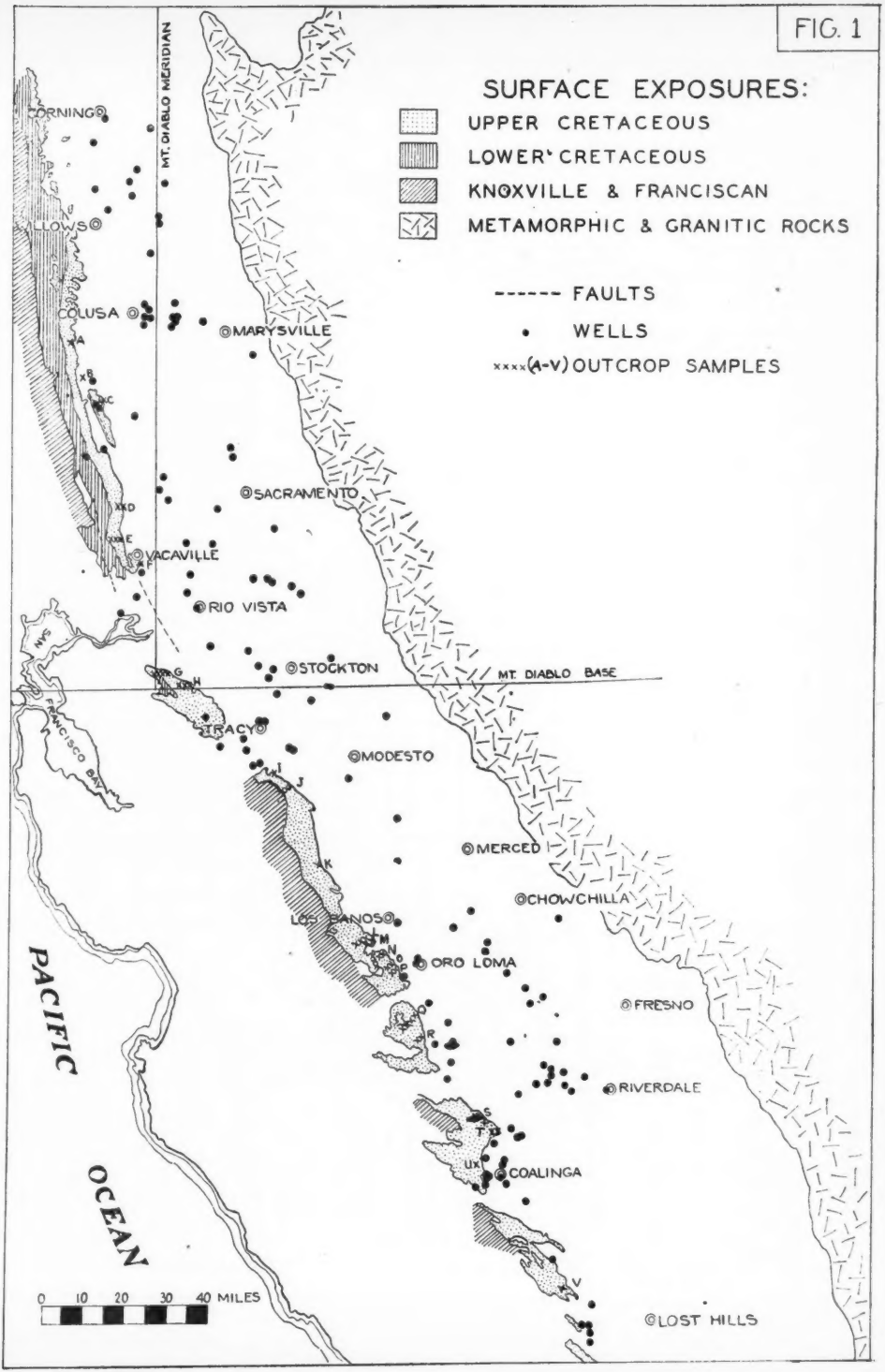


FIG. 1
SURFACE EXPOSURES:
UPPER CRETACEOUS
LOWER CRETACEOUS
KNOXVILLE & FRANCISCAN
METAMORPHIC & GRANITIC ROCKS
FAULTS
WELLS
(A-V) OUTCROP SAMPLES
MT. DIABLO MERIDIAN
MT. DIABLO BASE
CORNING
WILLOWS
COLUSA
MARYSVILLE
SACRAMENTO
VACAVILLE
RIO VISTA
STOCKTON
TRACY
MODESTO
MERCED
CHOWCHILLA
LOS BANOS
ORO LOMA
FRESNO
RIVERDALE
COALINGA
LOST HILLS
SAN FRANCISCO BAY
PACIFIC OCEAN
0 10 20 30 40 MILES

TENTATIVE FORAMINIFERAL CORRELATIONS OF UPPER CRETACEOUS FORMATIONS IN SACRAMENTO AND SAN JOAQUIN VALLEYS, CALIFORNIA

FIG. 2.

SAN JOAQUIN VALLEY									SACRAMENTO VALLEY		
COALINGA–ORTIGALITO AREA			PACHECO PASS – MT. DIABLO AREA				EAST SIDE OF SAN JOAQUIN VALLEY		WEST SIDE	EAST SIDE	
FORMATIONS		FORAMINIF. ZONES	FORMATIONS			FORAMINIF. ZONES	FORMATIONS	FORAMINIF. ZONES	FORMATIONS		FORAMINIF. ZONES
R. ANDERSON & R.W. PACK (1915)	M.B. PAYNE & J.Q. ANDERSON (1941)		R. ANDERSON & R.W. PACK (1915)	J.A. TAFF (1935) MT. DIABLO	F.M. ANDERSON (1941)		SUBSURFACE		J.M. KIRBY (1943) MARYSVILLE–BUTTES & PUTAH CREEK	W.P. POPENOE (1943)	
MORENO	DOS PALOS SH.	A-1	MISSING	MISSING	MISSING		SAND	A-1	"KIONE SAND"	MISSING	
	CIMA SD.										
	DOS PALOS SH.	A-2	MORENO		MORENO GROUP GARZAS	A-2	SHALE	A-2			
		B	MISSING		MISSING		MISSING		MISSING		
	MARCA SH.										
	TERRA LOMA	C									
	DOSADOS				QUINTO	C'	SILT OR	C'			
PANOCHE	BROWN MT. SD.	D-1	MORENO		MORENO	D-1	SILTY SH.	D-1	UNNAMED (SUBSURFACE)		D-1?
	RAGGED VALLEY SH.	D-2		MORENO	LOS GATOS	D-2	SAND	D-2			D-2?
		E				E	SHALE SAND	E			E?
	JOAQUIN RIDGE S.S.	F-1	PANOCHE	PANOCHE	GROUP JOAQUIN	F-1		F-1	FORBES GUINDA		F-1
		F-2				F-2					F-2
	ALCALDE SH.	G-1			PANOCHE BUTTE	G-1			FUNKS	MEMBERS VI & V MEMBER IV	G-1
	LOS GATOS S.S.										
	UPPER WALTHAM SH.	G-2	PANOCHE	CHICO	YOLO	G-2			SITES YOLO	MEMBERS III & II	G-2
	JUNIPER RIDGE S.S.	H			PIONEER GROUP BELLAVISTA	H	ABSENT BECAUSE OF OVERLAP OF ZONE F-1 ON BASEMENT OR ON PRE-CRETACEOUS ROCKS		CHICO SERIES VENADO		H
	LOWER WALTHAM SH.										
	LONG CANYON S.S.				GAINES						
	CURRY MT. SH.										

Regarding Figure 2 it should be remarked that the latest Cretaceous group of F. M. Anderson (Moreno) was previously called by him the Orestimba group, and that the Moreno formation he considers now not as the lowest but as the uppermost member of the group.[25] Also it must be emphasized that in the column dealing with the west side of the Sacramento Valley the foraminiferal zones are correlated not with the type localities of the formations as defined by Kirby but with the formations as shown by Kirby in the column of the Putah Creek section.[26] This has been done because in the lower 475 feet of the beds exposed on the crest and on the east flank of Rumsey Hills and referred to by Kirby as the type locality of the Forbes formation,[27] the writer has found a rich foraminiferal fauna identical with that present in the lower half of the division of Putah Creek section, called by Kirby the Funks formation. Besides, in the Putah Creek section there is a continuous and unbroken sequence of the Upper Cretaceous strata, whereas Rumsey Hills represents an isolated area faulted on the west side.

Figures 3, 4, and 5 represent lithologic character, formational divisions, and foraminiferal zones in the surface sections along the west side of the Great Valley and give additional illustration of the relation of the proposed zones with respect to the Upper Cretaceous formations described by various authors.

Figures 6 to 12 inclusive have been compiled to show variations in the lithologic character and thickness of the zones in subsurface sections. Intervals between the columns are proportional to the distances between corresponding wells.

By the diagrammatic map (Fig. 13) the writer attempts to elucidate the changes in the stratigraphic sequence of the Upper Cretaceous zones along the west and east sides of the Great Valley. Because of the small scale required to cover the whole area under discussion, the foraminiferal zones are pictured in the form of stripes of even width differentiated by certain symbols. The overlying formations listed in the legend of Figure 13 as upper Eocene, middle Eocene, and lower Eocene refer to the Tejon, Capay, Meganos, and Martinez Eocene stages as defined by B. L. Clark and H. E. Vokes.[28]

Figure 14 presents an attempt to give a generalized view of the stratigraphic relations of the foraminiferal zones by means of ten diagrammatic cross sections. In each section the depth to the first zone is plotted on a certain scale downward perpendicular to the line of that section, and zones below are illustrated in the same way as on the diagrammatic map.

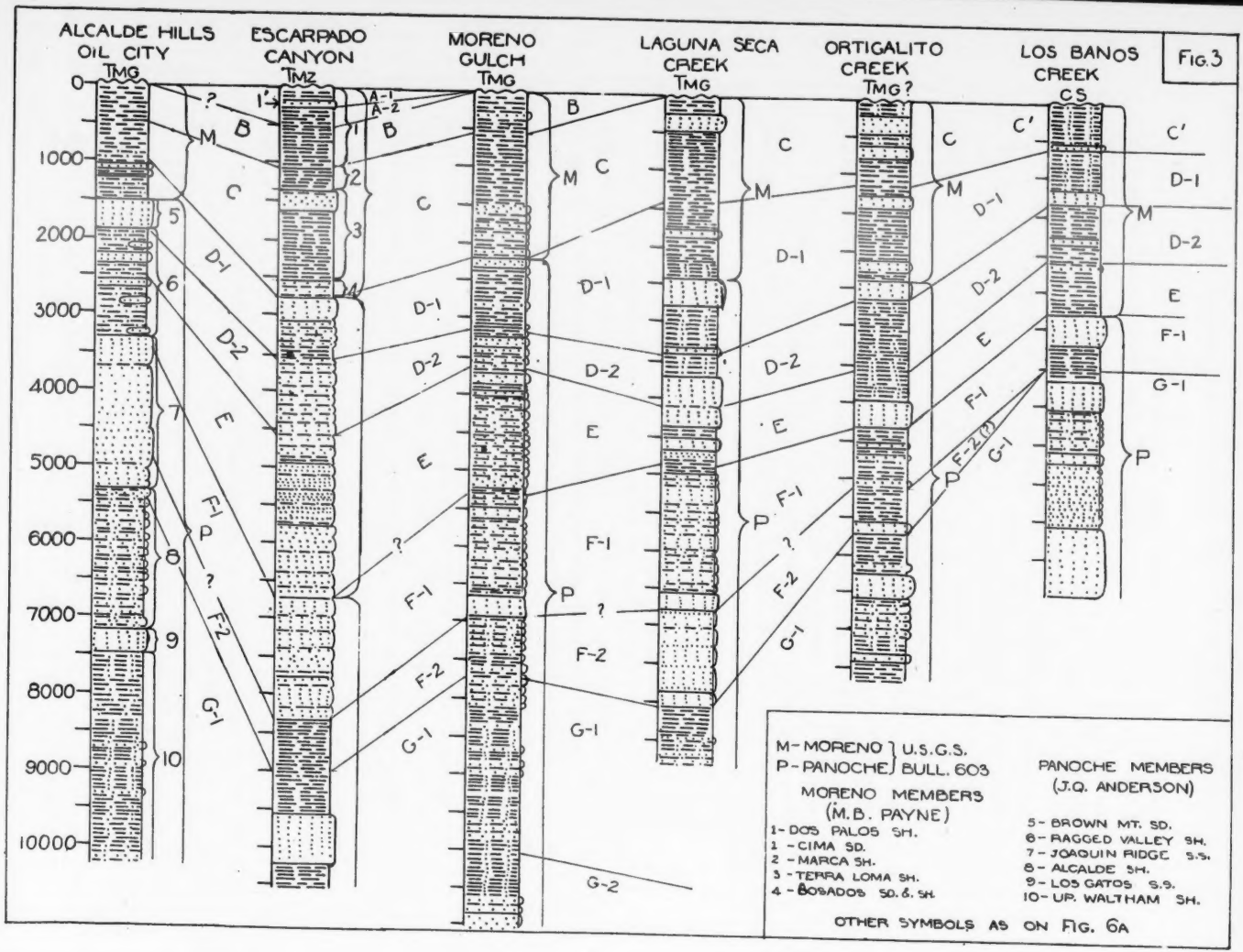
Regarding Figure 15 it should be noted that the contours on the map refer to the depth of the uppermost of the zones considered to be definitely Cretaceous

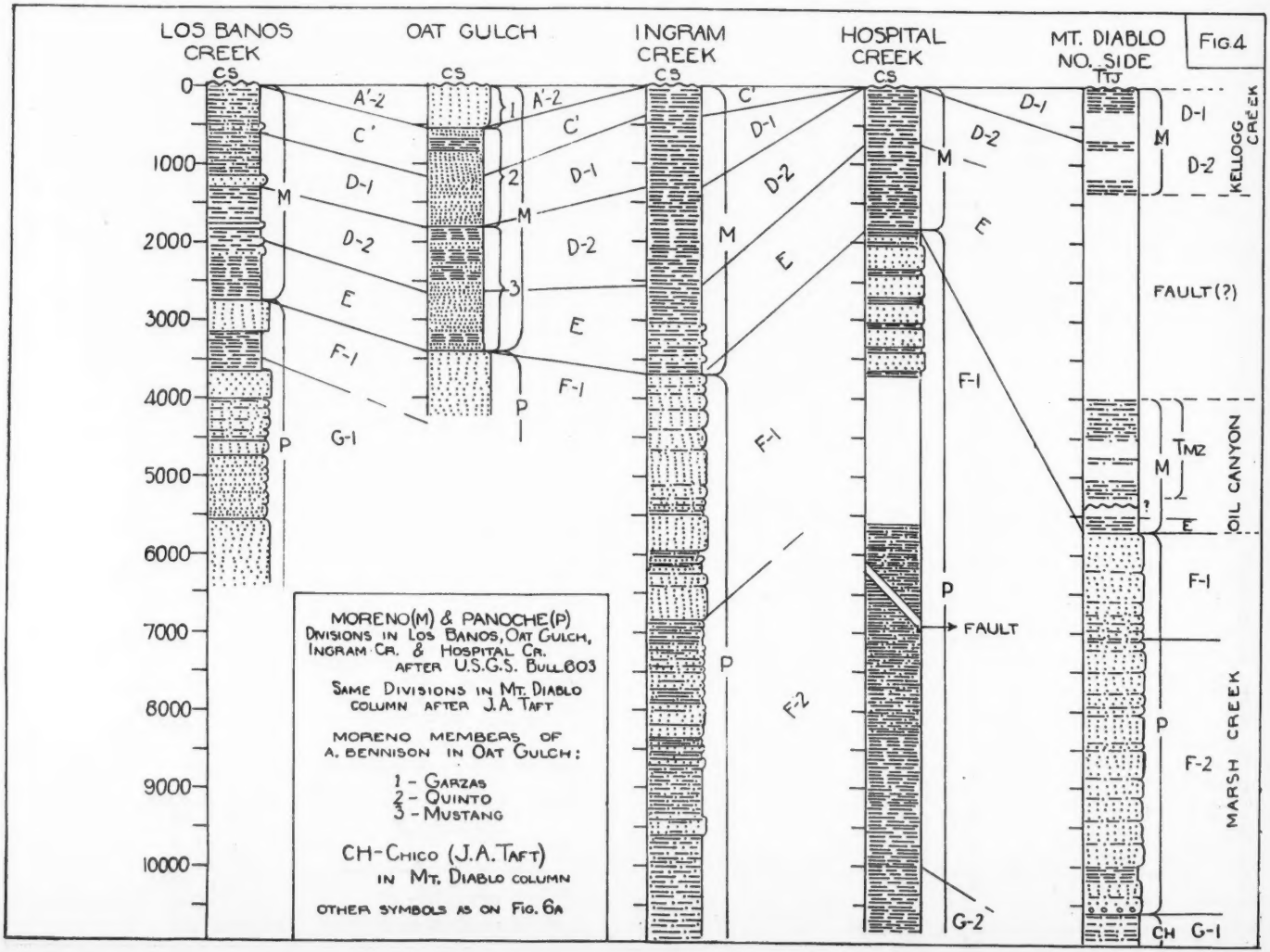
[25] Personal communication.

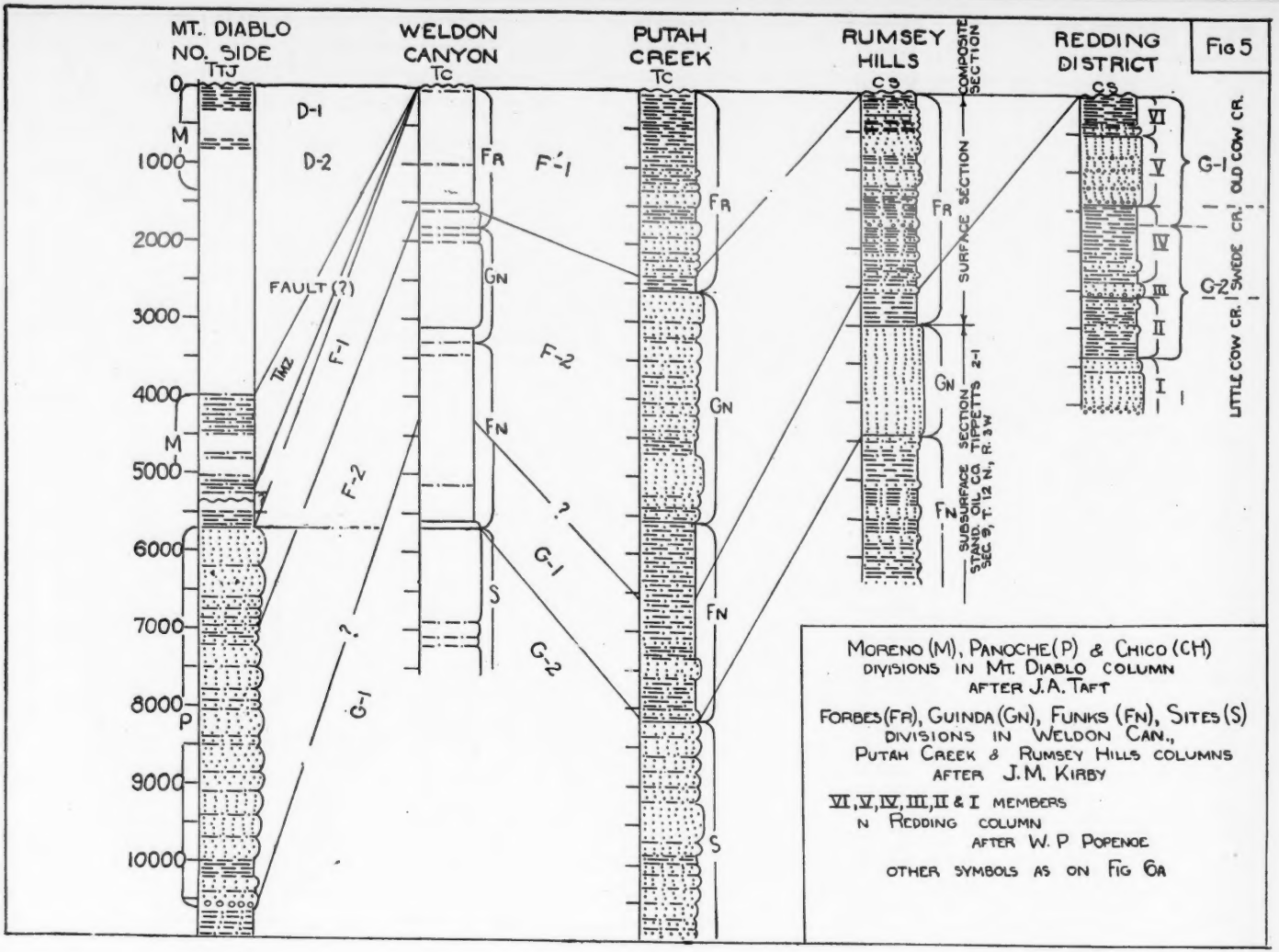
[26] J. M. Kirby, "Upper Cretaceous Stratigraphy of West Side of Sacramento Valley South of Willows, Glenn County, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 3 (1943), Fig. 2, opp. p. 289, and Fig. 7, opp. p. 299.

[27] *Ibid.*, p. 282.

[28] B. L. Clark and H. E. Vokes, "Summary of Marine Eocene Sequence of Western North America," *Bull. Geol. Soc. America*, Vol. 47 (June, 1936), p. 856.


ALCALDE HILLS
OIL CITY
TMG
ESCARPADO
CANYON
TMZ
MORENO
GULCH
TMG
LAGUNA SECA
CREEK
TMG
ORTIGALITO
CREEK
TMG?
LOS BANOS
CREEK
CS
Fig. 3
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
M - MORENO } U.S.G.S.
P - PANOCHE } BULL. 603
MORENO MEMBERS
(M.B. PAYNE)
1 - DOS PALOS SH.
1 - CIMA SD.
2 - MARCA SH.
3 - TERRA LOMA SH.
4 - BOSADOS SD. & SH.
PANOCHE MEMBERS
(J.Q. ANDERSON)
5 - BROWN MT. SD.
6 - RAGGED VALLEY SH.
7 - JOAQUIN RIDGE S.S.
8 - ALCALDE SH.
9 - LOS GATOS S.S.
10 - UP. WALTHAM SH.
OTHER SYMBOLS AS ON FIG. 6A


LOS BANOS CREEK
OAT GULCH
INGRAM CREEK
HOSPITAL CREEK
MT. DIABLO NO. SIDE
Fig. 4
CS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
A'-2
C'
D-1
D-2
E
F-1
G-1
M
P
1
2
3
F-2
G-2
FAULT
FAULT(?)
KELLOGG CREEK
OIL CANYON
MARSH CREEK
MORENO(M) & PANOCHE(P) DIVISIONS IN LOS BANOS, OAT GULCH, INGRAM CR. & HOSPITAL CR. AFTER U.S.G.S. BULL. 803
SAME DIVISIONS IN MT. DIABLO COLUMN AFTER J.A. TAFT
MORENO MEMBERS OF A. BENNISON IN OAT GULCH:
1 - GARZAS
2 - QUINTO
3 - MUSTANG
CH - CHICO (J.A. TAFT) IN MT. DIABLO COLUMN
OTHER SYMBOLS AS ON FIG. 6A


MT. DIABLO NO. SIDE
TTJ
WELDON CANYON
Tc
PUTAH CREEK
Tc
RUMSEY HILLS
Cs
COMPOSITE SECTION
REDDING DISTRICT
Cs
Fig 5
0
M
1000
2000
3000
4000
M
5000
6000
7000
8000
P
9000
10000
D-1
D-2
FAULT (?)
TMz
F-1
F-2
G-1
?
FR
GN
FN
S
F-1
F-2
G-1
G-2
FR
GN
FN
S
FR
GN
FN
SURFACE SECTION
SUBSURFACE SECTION
STAND. OIL CO. TIPPETTS 2-1
SEC 9, T. 12 N., R. 3 W.
VI
V
IV
III
II
I
G-1
G-2
LITTLE COW CR.
SWEDE CR.
OLD COW CR.
MORENO (M), PANOCHE (P) & CHICO (CH)
DIVISIONS IN MT. DIABLO COLUMN
AFTER J.A. TAFT
FORBES (FR), GUINDA (GN), FUNKS (FN), SITES (S)
DIVISIONS IN WELDON CAN.,
PUTAH CREEK & RUMSEY HILLS COLUMNS
AFTER J.M. KIRBY
VI, V, IV, III, II & I MEMBERS
N REDDING COLUMN
AFTER W.P. POPENOE
OTHER SYMBOLS AS ON FIG 6A

in age. As explained later, the zone designated in this paper by the capital letter A probably belongs to the Paleocene.

Paleogeographic maps (Fig. 16 and Fig. 17), have been compiled on the basis of all the knowledge obtained from the writer's study of the examined surface and subsurface samples, and also on the information reported by other workers.

DESCRIPTION OF ZONES

A ZONE (PRE-MARTINEZ PALEOCENE, "CHENEYAN STAGE")

To this zone the writer has assigned the series of beds penetrated by the Jergins Oil Company's Cheney Ranch well No. 1 (Sec. 29, T. 14 S., R. 13 E.) between the Martinez claystone[29] and the typical Moreno shale.

The series is separated from the Martinez claystone by glauconitic beds and is composed of light gray and white sands followed downward by silts and silty shales. The contact between these latter and the underlying Moreno shale is perfectly comformable.

The sands of the upper part of the series are barren of any organic remains. The silts and silty shales of the lower part contain abundant Foraminifera and other fossils.[30]

The foraminiferal content of the silts and silty shales overlying the Moreno in the Cheney Ranch well is characterized by four groups of the microfossils (Table II). The first is represented by four species so far not recorded in any known part of the California Tertiary-Cretaceous column.[31] The second includes several of the species commonly found in the Martinez formation.[32] To the third group belong some of the species which are diagnostic of the Upper Cretaceous zones described in this paper as zones C, C′, D-1 and D-2.[33] Finally, to the fourth group may be referred two species one of which ranges from the Meganos formation almost throughout the Upper Cretaceous beds,[34] and the other from the Meganos into the Moreno shale.[35]

The part of the Cheney Ranch well No. 1 section just described has been selected by the writer as the type of zone A. Its upper portion composed of light

[29] The claystone contains abundant Foraminifera typical of the Eocene E zone as described by Boris Laiming in his paper, "Some Foraminiferal Correlations in the Eocene of the San Joaquin Valley, California," *Proc. Sixth Pacific Sci. Cong.* (1939), p. 553.

[30] Including *Flabellum fresnoense* Durham.

[31] *Bathysiphon* sp. large form with black surface, *Robulus* sp. flat form, *Valvulineria lillisi* Cushman & Goudkoff, and *Valvulineria orolomaensis* Cushman & Goudkoff.

[32] *Bulimina* cf. *triangularis* Cushman & Parker, *Cibicides* cf. *ungeriana* (d'Orbigny) var., *Vaginulina* (*Marginulina*) cf. *plummeri* (Cushman), and some others.

[33] *Bolivina incrassata* Reuss; *Bulimina petroleana* Cushman & Hedberg: *Flabellina pilulifera* Cushman & Campbell; *Globulina lacrima* Reuss, var. *subsphaerica* Cushman & Goudkoff; anfl *Gyridina globosa* (Hagenow).

[34] *Silicosigmoilina californica* Cushman & Church.

[35] *Spiroplectoides clotho* (Grzybowski).

TABLE II

ZONAL RANGE OF MOST DIAGNOSTIC FORAMINIFERA SPECIES IN UPPER CRETACEOUS OF GREAT VALLEY

o = Characteristic occurrence; x = Occasional occurrence

	ZONES												
	A-2	A′-2	B	C	C′	D-1	D-2	E	E′	F-1	F′-1	F-2	G-1	G-2
Bolivina incrassata Reuss	x						o							
Bulimina petroleana Cushman & Hedberg	x	x				o	x							
Bulimina cf. *triangularis* Cushman & Parker	o	o												
Cibicides cf. *ungeriana* (d'Orbigny)	o													
Epistomina caracolla (Roemer)	x	x		x	x	x	x	x	o	x	x	x		
Flabellina pilulifera Cushman & Campbell	x			x	x	x	o	x			x			
Globulina lacrima Reuss, v. *subsphaerica* Cushman & Goudkoff	x						o							
Gyroidina globosa (Hagenow)	x	x				o	x	x						
Robulus sp. (flat form)	o	o												
Spiroplectoides clotho (Grzybowski)	o		o	x										
Vaginulina (*Margunilina*) cf. *plummerae* (Cushman)	o													
Valvulineria lillisi Cushman & Goudkoff	o													
Valvulineria orolomaensis Cushman & Goudkoff	x	o												
Dentalina megapolitana Reuss		x			x		x	x	o		x			
Gaudryina filiformis Barthelin			o	x										
Anomalina cf. *clemetiana* (d'Orbigny)				o										
Bulimina prolixa Cushman & Parker				o	o	x								
Planulina nacatochensis Cushman				o	o	x								
Siphogenerinoides clarki Cushman & Campbell, v. *costifera* Cushman & Goudkoff				x	x	o								
Siphogenerinoides whitei Church				o										
Siphogenerinoides clarki Cushman & Campbell					x	o								
Cibicides cf. *coonensis* (W. Berry)						o								
Eponides ingramensis Cushman & Goudkoff						o								
Gaudryina navarroana Cushman, v. *crassaformis* Cushman & Campbell						x	o							
Globotruncana arca (Cushman)						x	o	o	x	x	x	x	x	
Nodosaria spinifera Cushman & Campbell						x	o	x						
Anomalina cf. *rubiginosa* Cushman							o							
Bulimina obtusa d'Orbigny							x	o	x	x	x		x	
Bulimina spinata Cushman & Campbell							o							
Chrysalogonium cretaceum Cushman & Church							x	x	x	?	o	?	x	
Guembelina globulosa (Ehrenberg)							x	x	x	x	o	x	x	

	ZONES													
	A-2	A′-2	B	C	C′	D-1	D-2	E	E′	F-1	F′-1	F-2	G-1	G-2
Marginulina cf. *bronni* (Roemer)							o	x						
Marginulina elongata d'Orbigny							o	x	x	x	x			
Marginulina striato-carinata Cushman & Campbell							o	x	x		x			
Ventilabrella ornatissima Cushman & Church							o	x	x	x	x	x	x	
Anomalina henbesti Plummer								o		x				
Bathysiphon alexanderi Cushman								x	x	x	o	x	x	
Bathysiphon taurinensis Sacco								x		o		x	x	x
Eponides spinea (Cushman)								x		x	x	o	x	
Gyroidina quadrata Cushman & Church								x		x	?	x	o	
Gyroidina subangulata Plummer								o		x		x	x	
Marginulina jarvisi Cushman								x		x	o	x		
Marsonella oxycona (Reuss)								o		x	x	x	x	x
Haplophragmoides colusaensis Cushman & Goudkoff									o		x			
Ammodiscoides turbinatus Cushman										o		x	x	x
Cribrostomoides cretacea Cushman & Goudkoff										o	o	o		
Cribrostomoides (?) sp.										o	o	o	x	x
Gaudryina rudista Sandidge, v. *diversa* Cushman & Goudkoff										o	o	o	x	x
Globotruncana canaliculata (Reuss)										x	x	x	o	o
Haplophragmoides eggeri Cushman, v. *minuta* Cushman & Goudkoff										o	x	o		
Nodellum sp.										o		x	x	x
Trochamminoides proteus Karrer										o	x			
Bathysiphon perampla Cushman & Goudkoff										x	x	o		
Eponides umbonella (Reuss)											x	x	o	o
Marginulina curvisepta Cushman & Goudkoff											o	x		
Marginulinopsis decurse-costata Thalmann											x	x	o	
Gaudryina retusa Cushman												x	o	o
Gyroidina florealis White												o	x	x
Stensioina excolata (Cushman)												x	o	o
Trochammina sp. (large, flat form)												o		
Amphimorphina sp.													o	o
Gaudryina pyramidata Cushman													o	o
Planularia tricarinella (Reuss)													o	o
Pleurostomella cf. *subnodosa* Reuss													o	o
Reusella californica Cushman & Goudkoff													o	
Cibicides stephensoni Cushman														o
Vaginulina cf. *kochii* Roemer														o±

gray and white sands is designated by symbol A-1, and the foraminiferal silts and silty shales of the lower portion by symbol A-2.

From the foregoing discussion one can see that both by its stratigraphical position and micro-organic content zone A should be considered as a connecting link between the Moreno shale and the Martinez formation. Regarding the question of the age of the zone the same difficulty is encountered that always arises when one deals with the strata intermediate between two well defined series: Eocene and Oligocene, Miocene and Pliocene, and the like. According to recent views expressed by California geologists, the deposits generally designated as the Martinez formation should be referred to the Paleocene.[36] The age of the Moreno shale is commonly accepted as the Upper Cretaceous, equivalent of the Maestrichtian or Danian stages of Europe, or, possibly, embracing both of these stages.[37] Thus, the zone A should be considered either pre-Martinez Paleocene, or post-Moreno Cretaceous. The writer favors the Paleocene because (1) within lower part of the A zone in the Cheney Ranch well No. 1, 1,109 feet below the beds with the Martinez microfauna and only 200 feet above the top of the typical Moreno shale there has been recorded *Flabellum*, and (2) this coral, according to H. G. Schenck,[38] has been found throughout the world, but nowhere in the Cretaceous beds, its lowest record being the Paleocene.

The A zone of the same lithologic character and in the same stratigraphical position as in the Cheney Ranch well No. 1 is also found in a well drilled in T. 15 S., R. 15 E., near the town of Tranquility (column in Fig. 9), and in a well in T. 12 S., R. 11 E., southwest of the town of Oro Loma (columns in Fig. 8b and Fig. 9). In the latter well, however, the zone underlies not the Martinez formation but the upper Eocene beds.

In other wells along the foothills on the west side of the San Joaquin Valley between Coalinga and Panoche Creek, the silty shales and shales with the microfauna typical of the A-2 subzone were penetrated directly below the Martinez, whereas the sands forming A-1 subzone in the Cheney Ranch well were absent.

In outcrops on the west side of the San Joaquin Valley, as far as it is known to the writer, equivalents of the A-1 and A-2 subzones can be detected only in

[36] Bruce Clark, "Notes on California Tertiary Correlations," *California Div. Mines Bull. 118*, Pt. 2 (1941), p. 187.
Robert T. White, "Paleocene Mollusks from Panoche Creek, California," *Program*, summer meeting, 1939, Geol. Soc. America, abstract on p. 32.

[37] F. M. Anderson, "Synopsis of the Later Mesozoic in California," *California Div. Mines Bull. 118*, Pt. 2 (1941), p. 185.
N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges of California," *ibid.*, p. 134.
Hubert Schenck," *Acila princeps*, a New Upper Cretaceous Pelecypod from California," *Jour. Paleont.*, Vol. 17, No. 1 (1943), p. 66.
Chester Stock, "The Cretaceous Vertebrate Record of California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 11 (1941), p. 2094.
N. L. Taliaferro, "Cretaceous and Paleocene of Santa Lucia Range, California," *ibid.*, Vol. 28, No. 4 (1944), p. 506.

[38] Personal communication.

Escarpado Canyon within the uppermost part of the Moreno, as mapped by R. Anderson and Pack, or more definitely in the Dos Palos shale and Cima sand members of the Moreno as described by Payne.[39] The correlation of these members with the A zone (Fig. 3) is based on the occurrence of one of the most typical of A-2 foraminiferal species[40] at a depth 150 feet below the base of the Cima sand which is considered as correlative with the A-1 subzone.

The farthest easterly extension of A-2 subzone in the southeastern part of the San Joaquin Valley is limited by a line drawn from the Cheney Ranch well through the well near Tranquility and toward the northwestern part of the Helm oil field (T. 16 S., R. 17 E.). The wells within this area cored white sands assumed to represent the A-1 subzone, and farther down a small thickness of silty shales with a microfauna typical of subzone A-2 (Fig. 9). The series unconformably underlies the beds of Martinez age, and unconformably overlies the Upper Cretaceous beds referred in this paper to zone D-1.

Another type of the pre-Martinez Paleocene beds (zone A of the Cheney Ranch well) is developed within the part of the San Joaquin Valley roughly limited by lines drawn from the McDonald Island gas field (T. 2 N., R. 4 E.) to the center of T. 12 S., R. 11 E., thence to Riverdale and back toward the McDonald field. These beds form a series composed of sands in the upper part and silts in the lower part and are found below the Tejon, Domengine, or Martinez formation, and above the Cretaceous beds assigned in this paper to the C′ or D-1 zone. The series is assumed to be equivalent to the pre-Martinez of the Cheney Ranch well for the following reasons.

1. It occupies a similar stratigraphical position, which similarity can be demonstrated by the correlation of the Cheney Ranch well with another well in the same township, and with the wells drilled along the line from Oro Loma toward Chowchilla (Fig. 8b).

2. The topmost sand of the series (called by many field geologists the "top of the Cretaceous) is marked by a peculiar pattern of the electric-log curve closely resembling that corresponding with the top of the white sand of subzone A-1 in the Cheney Ranch well.

3. The lower silty part of the series (called in this paper the A′-2 subzone) is characterized by sporadic occurrence of several of the species found in the A-2 subzone of the Cheney Ranch well,[41] including some of those which seem to be restricted to this subzone,[42] or not known to occur in any of the older zones.[43]

[39] Max B. Payne, "Moreno Shale, Panoche Hills, Fresno County, California," abstract, Cordilleran Section (1941), p. 19.

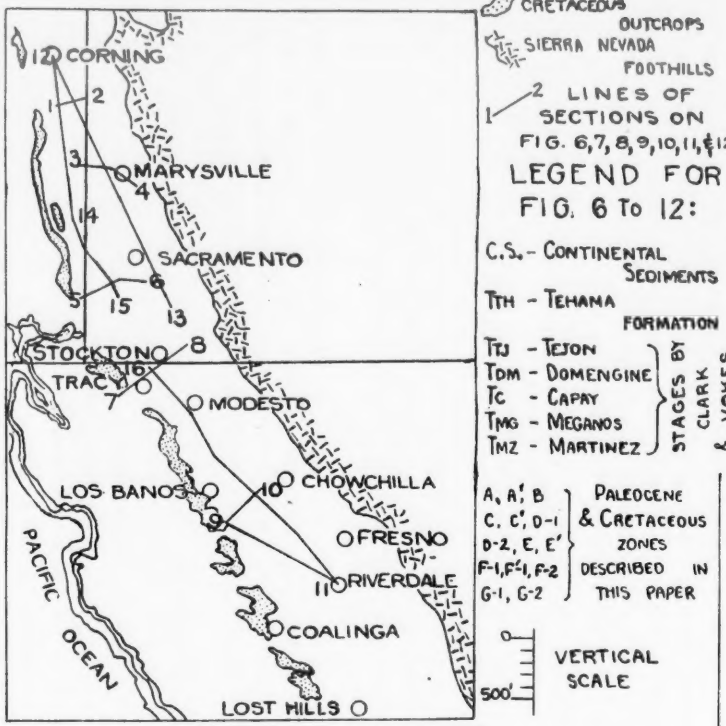
[40] *Valvulineria lillisi* Cushman and Goudkoff.

[41] *Epistomina caracolla* (Roemer), *Gyroidina depressa* (Alth) and some others.

[42] *Robulus* sp. flat form, and *Valvulineria orolomaensis* Cushman & Goudkoff.

[43] *Bulimina* cf. *triangularis* Cushman & Parker.

FIG. 6a



CRETACEOUS OUTCROPS

SIERRA NEVADA FOOTHILLS

1 2 LINES OF SECTIONS ON FIG. 6, 7, 8, 9, 10, 11, & 12

LEGEND FOR FIG. 6 TO 12:

C.S. - CONTINENTAL SEDIMENTS

TTH - TEHAMA FORMATION

TTJ - TEJON
TDM - DOMENGINE
TC - CAPAY
TMG - MEGANOS
TMZ - MARTINEZ
} STAGES BY CLARK & VOKES

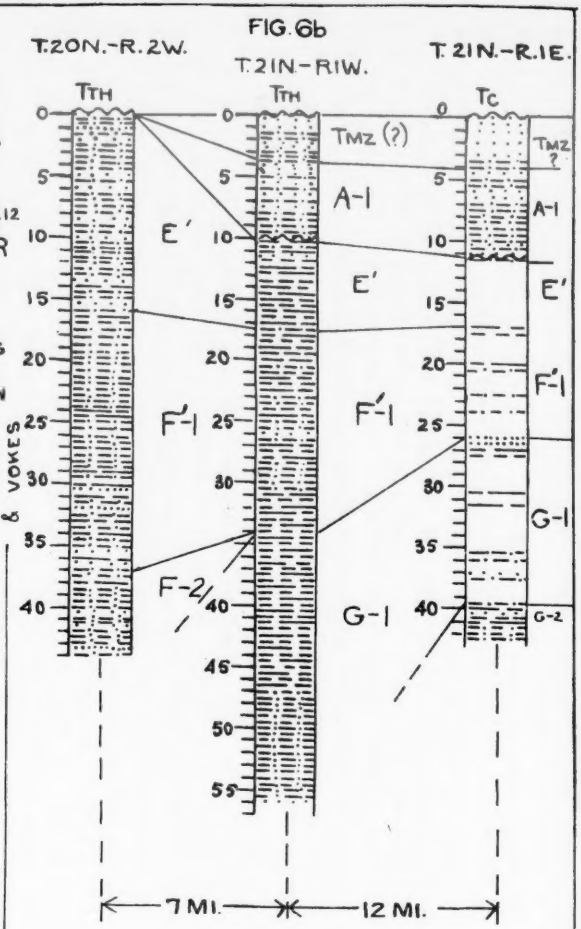
A, A', B
C, C', D-1
D-2, E, E'
F-1, F'-1, F-2
G-1, G-2
} PALEOCENE & CRETACEOUS ZONES DESCRIBED IN THIS PAPER

0 500' VERTICAL SCALE

LITHOLOG SYMBOLS

- ·o·o· PEBBLY SD. & CONGLOMER.
- · · · · SAND & SANDSTONE
- ····· SILT & SILTSTONE
- -·-·- SILTY & SANDY CLAYSTONE OR SHALE
- ≡≡≡ COMPACT CLAYSTONE OR SHALE
- V V V VOLCANIC ROCKS
- ≈≈≈ PRE-CRETACEOUS SEDIMENTS
- ⁄⁄⁄⁄⁄ IGNEOUS & METAM. ROCKS
- ∿∿∿ HIATUS

FIG. 6b



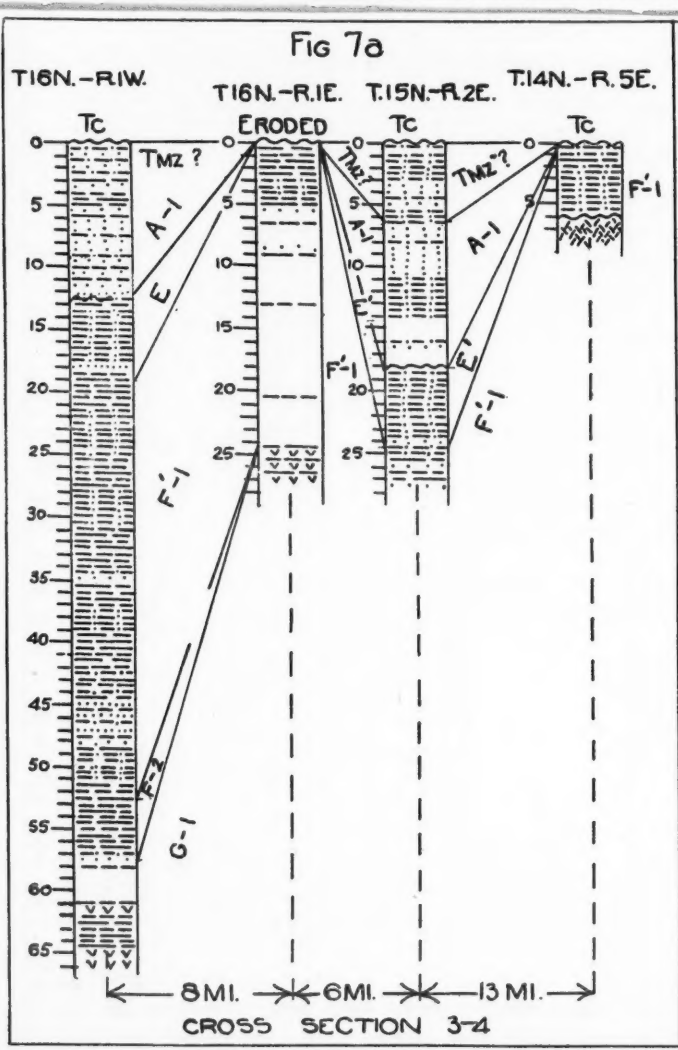
CROSS SECTION 1-2

COMPACT CLAYSTONE OR SHALE

HIATUS

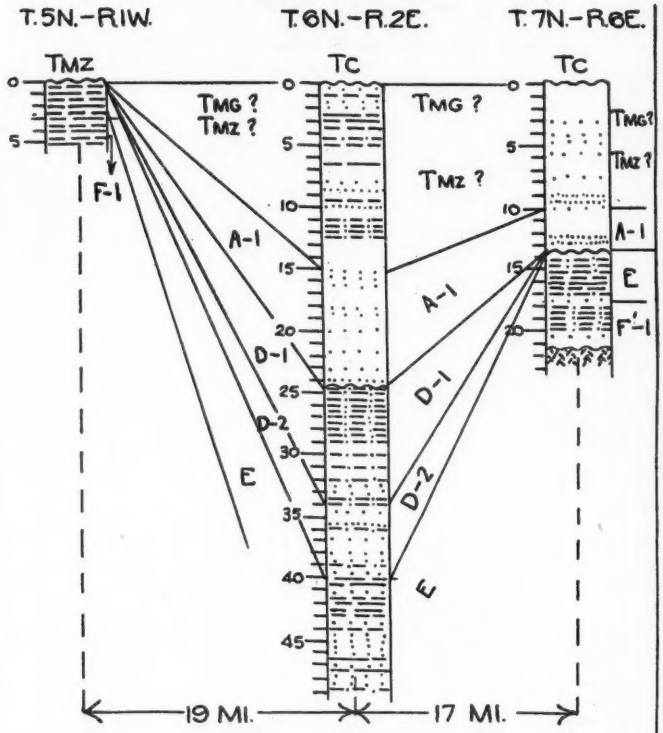
CROSS SECTION 1-2

Fig 7a

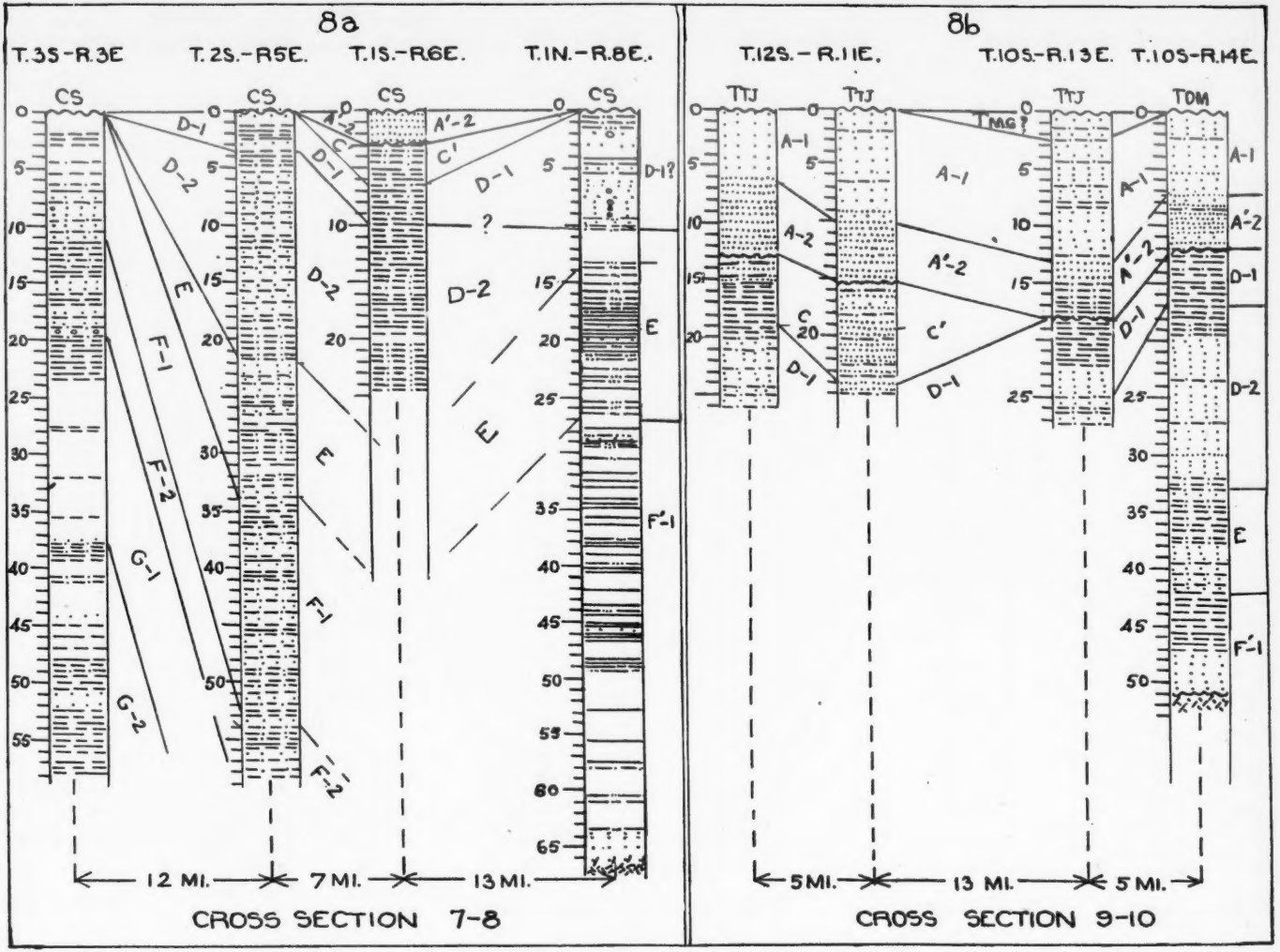


CROSS SECTION 3-4

Fig 7b



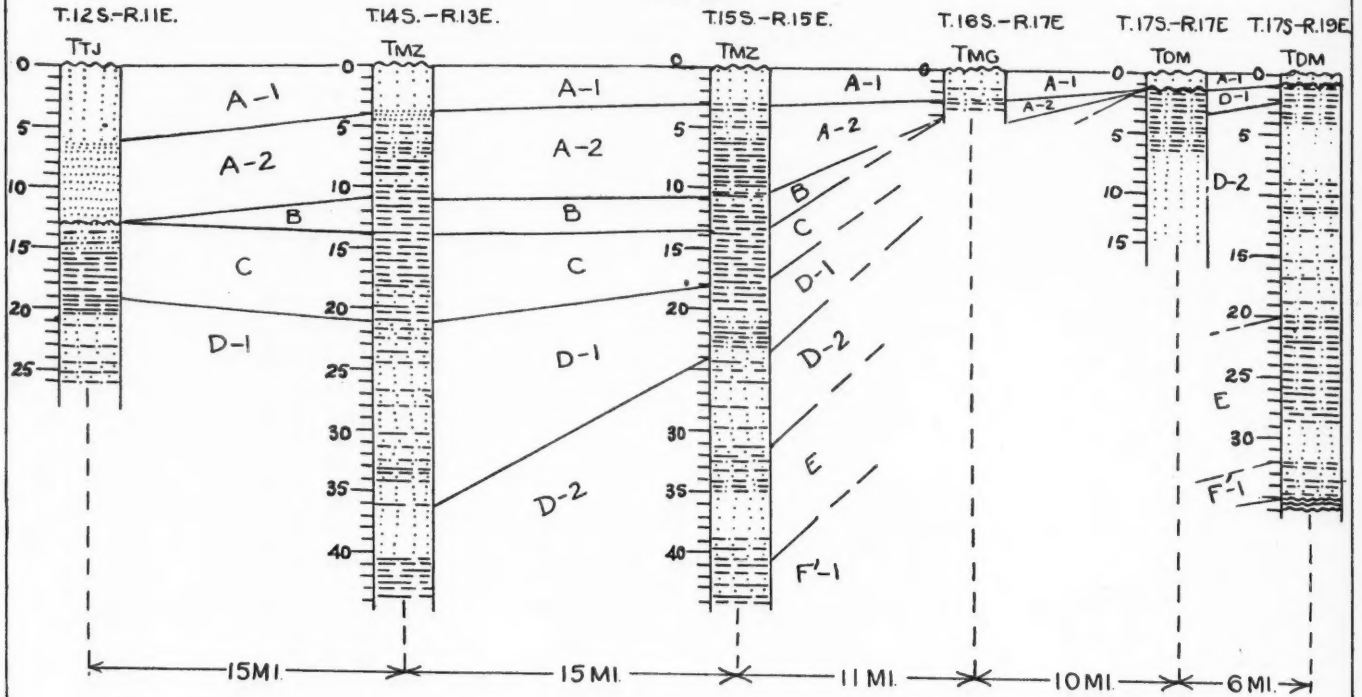
CROSS SECTION 5-6


8a
T.3S-R.3E
T.2S.-R5E.
T.1S.-R6E.
T.1N.-R.8E.
CS
D-1
D-2
E
F-1
F-2
G-1
G-2
A'-2
C'
D-1?
?
D-2
E
F'-1
12 MI.
7 MI.
13 MI.
CROSS SECTION 7-8
8b
T.12S.-R.1IE.
T.10S-R.13E.
T.10S-R.14E.
TTJ
TMG?
TDM
A-1
A-2
C
D-1
A'-2
C'
D-1
A-1
A'-2
D-1
D-2
E
F'-1
5MI.
13 MI.
5 MI.
CROSS SECTION 9-10

CROSS SECTION 7-8

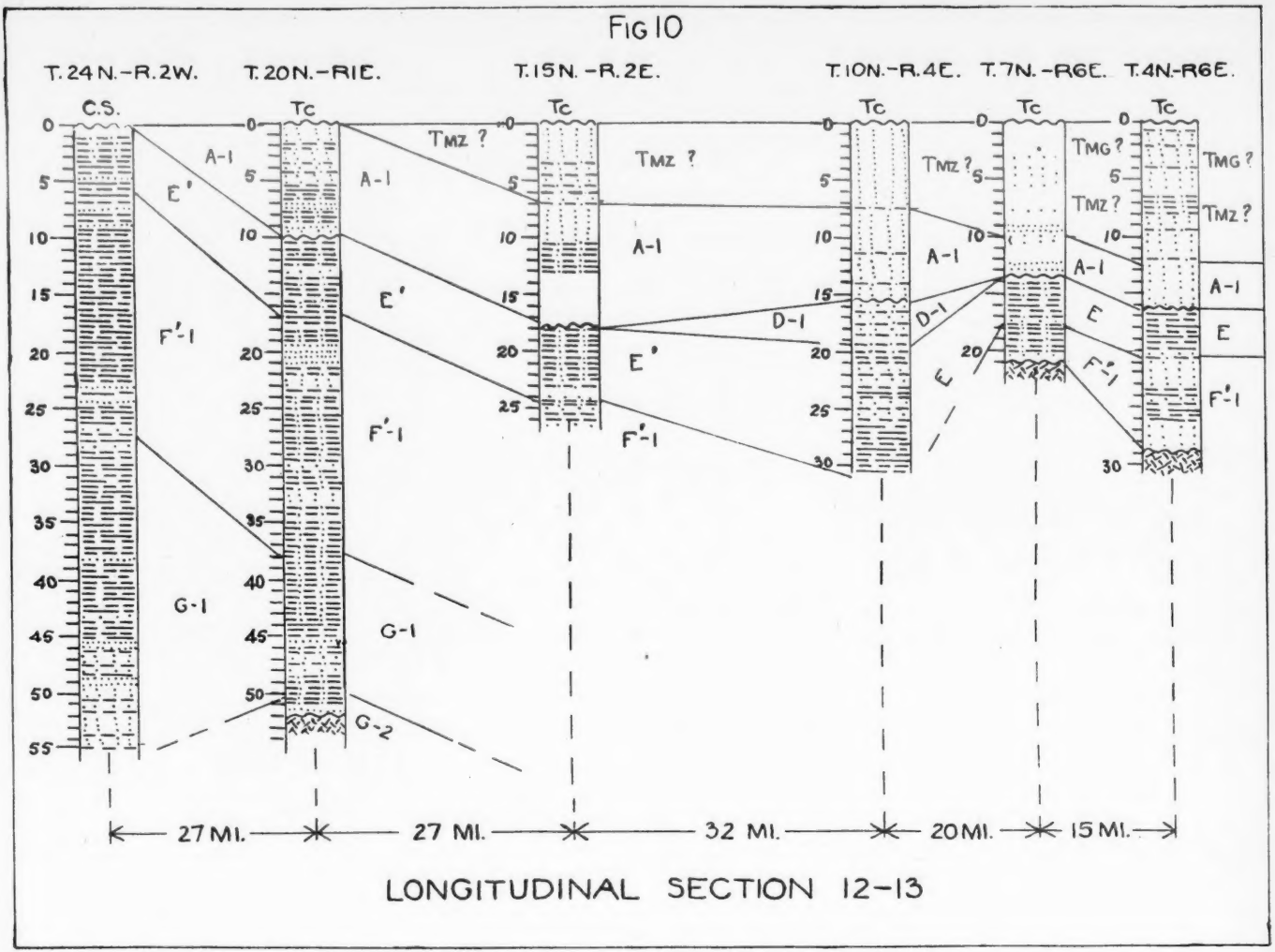
CROSS SECTION 9-10

FIG. 9



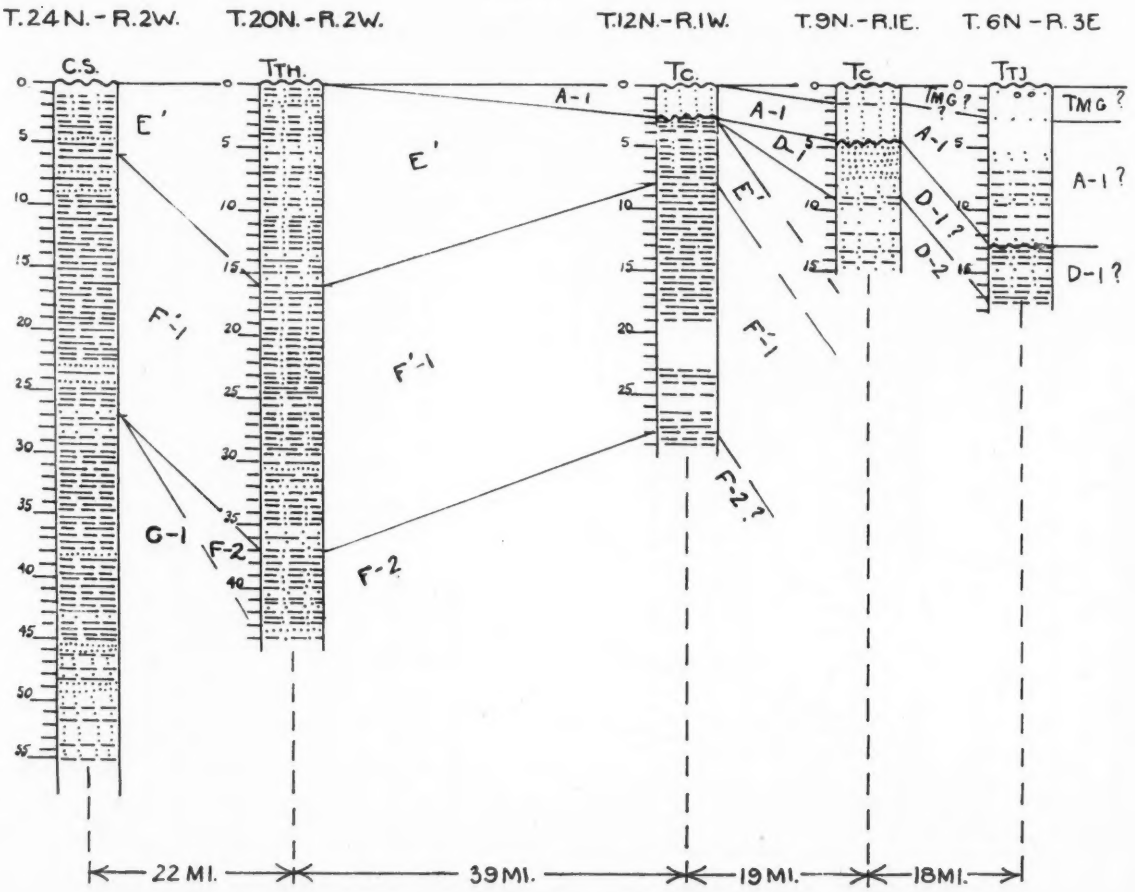
SECTION 9-11

FIG 10



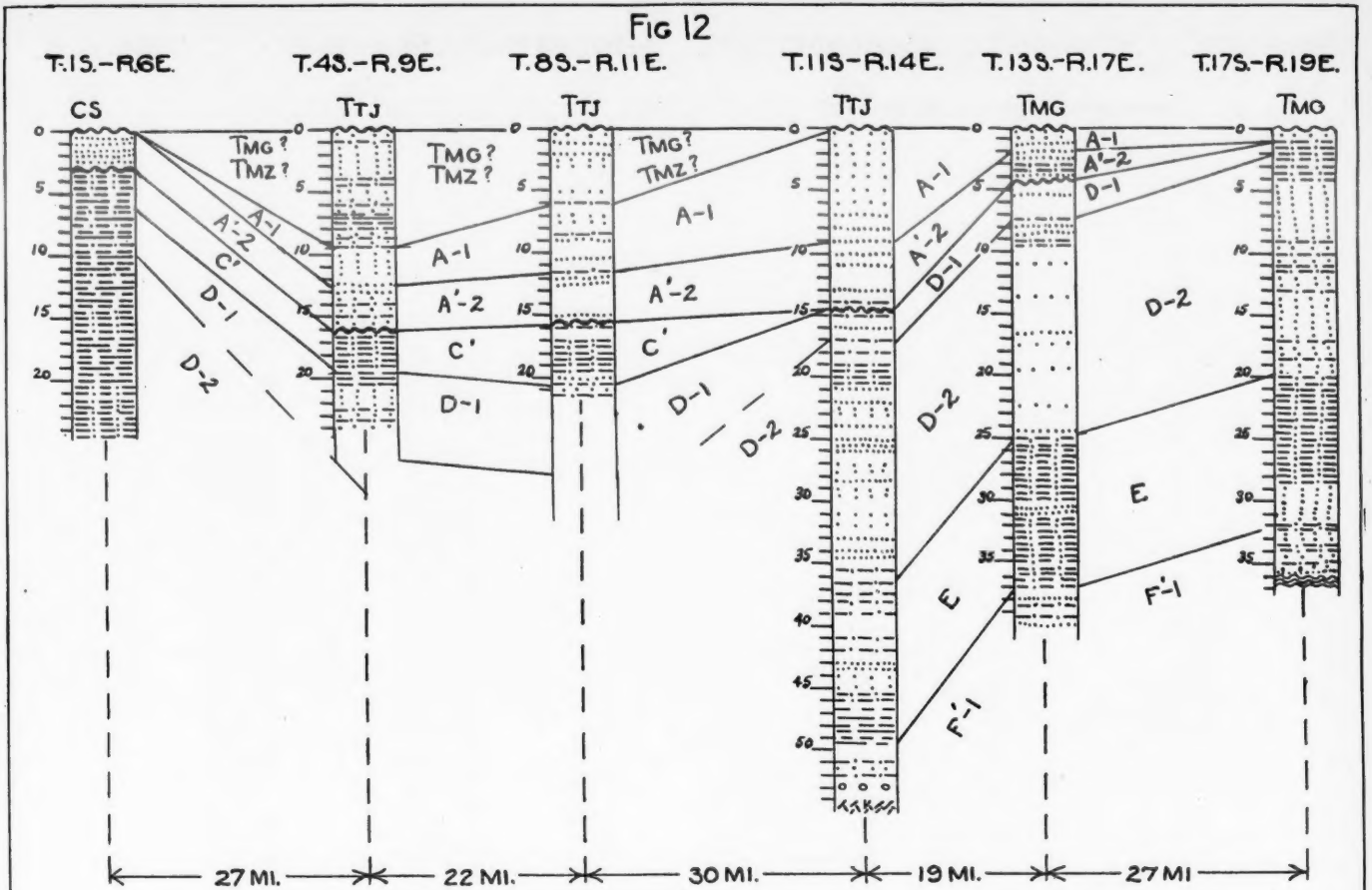
LONGITUDINAL SECTION 12-13

Fig. 11



LONGITUDINAL SECTION 12-15

Fig 12



LONGITUDINAL SECTION 16-11

As one can learn from the correlation charts (Fig. 8b and Fig. 12), the series just described (embracing the A-1 and A′-2 subzones) is overlain by beds ranging in age from the Tejon to the Meganos, and is underlain by the Cretaceous beds identified as the C′ or D-1 zone. Due to these unconformities the thickness of the series varies from less than 100 feet in a well near Riverdale (T. 17 S., R. 19 E., Fig. 12) to about 1,500 feet in some of the wells between Chowchilla and Modesto (T. 11 S., R. 14 E., Fig. 12).

To the A′-2 subzone, as just described, belongs also, in the writer's belief, the so-called Garzas sand. This sand was first defined by F. M. Anderson as the uppermost member of the Moreno group,[44] and by Bennison as the second from the top "Moreno member."[45] Later, Payne, on the basis of his field work, reported that the Moreno group of F. M. Anderson and the "Moreno members" of Bennison "appear to underlie the Moreno of the type area."[46] From personal communication the present writer knows that F. M. Anderson had fully endorsed the interpretation made by Payne, and now is considering the Garzas sand as a formation older than the Moreno at its type locality.

Microfaunal study of samples from the Garzas sand and from the underlying formations exposed along Oat Gulch in Sec. 11, T. 8 S., R. 7 E. (Fig. 4) reveals that the Garzas sand contains a variety of Foraminifera species, most of which are represented by a few specimens and belong to the microfossils typical of the Cretaceous zones here designated D-1 and D-2.[47] Yet, together with these there is present one species which appears to be limited to the A-2 subzone,[48] and another one not known to occur below the same subzone.[49] Deeper in the section is a faunule composed almost exclusively of very abundant specimens of the species most characteristic of the lower part of the Moreno[50] (C and C′ zone in this paper) but ranging also into the uppermost Panoche beds (D-1 zone). The remaining species in the Garzas sand disappear immediately below its base but are found again 500 feet deeper where they mark the base of the C′ zone, below which is a normal sequence of zones D-1, D-2, E, and F-1 (Fig. 4). These features lead the writer to conclude: that most of the Foraminifera species found in the Garzas must be considered as redeposited; that the Garzas sand itself is equivalent of the part of the Cheney Ranch well described as the A-2 subzone; and that

[44] F. M. Anderson, *California Div. Mines Bull. 118*, Pt. 2 (1941), p. 186.

[45] Allen Bennison, "Later Cretaceous of the Diablo Range," read at the meeting of the Le Conte Club, Stanford University, March 2, 1940. The uppermost of his "Moreno members" Bennison called Volta sand.

[46] Max B. Payne, *op. cit.*

[47] *Bolivina incrassata* Reuss, *Cibicides* cf. *coonensis* (W. Berry), *Gaudryina navarroana* Cushman v. *crassaformis* Cushman & Campbell, *Globotruncana arca* (Cushman), *Gyroidena globosa* (Hagenow), *et cetera.*

[48] *Valvulineria orolomaensis* Cushman & Goudkoff.

[49] *Bulimina* cf. *triangularis* Cushman & Parker.

[50] *Bulimina prolixa* Cushman & Parker.

the Garzas is unconformably underlain by a normal sequence of the Cretaceous beds corresponding with zones C′, D-1, D-2, E, and F′-1.

As it has been emphasized by Taliaferro,[51] very valuable information concerning the age of the Garzas sand has been furnished by the study of mosasaurs made by C. L. Camp.[52] *Kolposaurus bennisoni* recognized by Camp about 225 feet above the base of the Garzas may be according to Camp, "younger than any previously recorded Maestrichtian mosasaur" and "is probably post-Maestrichtian in age," whereas *Kolposaurus tuckeri* found near the type of the Moreno is "associated with Maestrichtian invertebrates."[53]

A ZONE IN SACRAMENTO VALLEY

One of the wells in the McDonald gas field (T. 2 N., R. 4 E.), before reaching the Cretaceous C′ zone, cored silty shale with the microfaunal content similar to that of the A′-2 zone as developed in the middle part of the San Joaquin Valley.

Part of the section penetrated by a well north of Rio Vista field (see column in T. 6 N., R. 2 E. in Fig. 7b) between presumably Martinez beds and the Cretaceous D-1 zone is composed of a series of sands and silts at the base of which has been recorded the same coral that was found in the lower part of the A-2 subzone in the Cheney Ranch well.[54]

Correlation of the well just mentioned (T. 6 N., R. 2 E.) with the wells in the Lodi Community area (T. 4 N., R. 7 E.) and with those drilled south, west, and north of Sacramento (T. 7 N., R. 6 E., T. 9 N., R. 1 E., and T. 10 N., R. 4 E.) suggests that the white sands encountered by these wells above various horizons of the Cretaceous strata (Fig. 7b, 10, and 11) may be equivalent to the A-1 sub-

[51] N. L. Taliaferro, *op. cit.*, pp. 505–06.

[52] C. L. Camp, *op. cit.*, pp. 2, 26, and 47.

[53] An indirect evidence of the presence of redeposited fossils in the Garzas sand may be found in Taliaferro's discussion of the fauna from the Asuncion formation (*op. cit.*, pp. 501–08). The Foraminifera from Asuncion shale were reported to Taliaferro by Lois T. Martin as the Upper Cretaceous, "approximately the same age as the Moreno shale north of Coalinga." (On the basis of his study of the same material obtained from H. G. Schenck, the present writer believes that the microfauna in question can not be older than the lower part of the Moreno.) As regards the Asuncion molluscan fauna Taliaferro, stating that according to B. L. Clark this fauna contains a great many species in common with the so-called Garzas fauna, says that he noticed a striking similarity of the Asuncion material with Popenoe's *Glycimeris veatchii* fauna in the Santa Ana Mountains. And this latter fauna, according to Popenoe's own statement ("Cretaceous Formations on the Northern Santa Ana Mountains," *California Div. Mines Bull. 118*, Pt. 3, p. 366), "is closely related to the younger fauna of the Redding region and the faunas . . . from Chico and Buttes Creeks in Buttes County." The present writer's microfaunal study of samples from the outcrops in the Redding region leaves no doubt that even the youngest of the sampled beds belong to some of the earliest Upper Cretaceous strata (zone G-1 in this paper), and are microfaunally correlative with the horizon in the Moreno Gulch surface section about 5,500 feet stratigraphically below the base of the Moreno. Also from personal communication the writer knows that F. M. Anderson considers the beds exposed in Buttes and Chico creeks as equivalent to the "black clay shale" described by R. Anderson and Pack as the lower member of Joaquin Ridge and shown by them on their generalized section, about 5,500 feet below the base of the Moreno (*U. S. Geol. Survey Bull. 603*, p. 40, and Fig. 2 on p. 26). This conflicting correlation of the Asuncion Mollusca with the Garzas fauna (and Asuncion Foraminifera with the Moreno microfauna) on one side, and with the beds 5,500 feet below the base of the Moreno on the other side, leads to the conclusion that at least some of these Mollusca either have a very long range or should be considered as redeposited from older Cretaceous beds.

[54] *Flabellum fresnoense* Durham.

zone of the Cheney Ranch well. This assumption is supported by the lithologic similarity of the sands and by the pattern of the electric-log curves at the top of the sands resembling that marking the top of the sand identified as the A-1 subzone in the wells in the middle part of the San Joaquin Valley

With less certainty the A-1 subzone has been tentatively recognized in the subsurface strata within the part of the Sacramento Valley embracing the Colusa-Buttes area on the south and the Willows-Corning area on the north.

In connection with the assumed presence of the A-1 subzone in the Sacramento Valley, it may be appropriate to refer to a considerable difference of opinion regarding the top of the Cretaceous in the Marysville Buttes. Williams, in his first description of the stratigraphy of this area, placed the top of the Chico series directly below the Marysville formation which he classified as the middle Eocene, Meganos.[55] He emphasized, however, that it is difficult to determine the exact contact of the Chico with the overlying Eocene.[56] Later, as reported by Anderson and Russell, Williams stated that in view of the recent discoveries, the Ione white sands (overlying the Marysville formation and previously assigned by Williams also to a part of the Meganos) "are in reality interbedded with the Cretaceous sediments."[57] In most recent publications on the Marysville Buttes, Johnson notes that "the Chico formation of Marysville Buttes is now known to include Williams' Marysville formation some of his supposed Ione and a portion of his Butte gravels."[58]

The present writer believes that the wide discrepancy in the views on the "Eocene-Cretaceous" contact in the Marysville Buttes should be explained by the numerous occurrences of redeposited Cretaceous fossils, which occurrences can be demonstrated by the following results of the writer's microfaunal study.

(a) In one of the Sutter Buttes wells, in T. 15 N., R. 1 E., the first Foraminifera typical of the F′-1 zone were found 1,510 feet above the normal sequence of the Cretaceous beds beginning with zone E′.
(b) In another well in the same township Foraminifera of the F′-1 zone were found 375 feet above the top of the normal Cretaceous sequence, with the E′ zone at the top.
(c) A well west of Buttes (T. 16 N., R. 1 W.) furnished core material with some of the F′-1 zone Foraminifera 3,160 feet above the E′ zone forming the top of the normal Cretaceous sequence.
(d) In a well in T. 12 N., R. 1 W., the Foraminifera typical of the G-1 zone were found together with the Capay Foraminifera 594 feet above the top of the normal Cretaceous sequence beginning with the E′ zone.
(e) In the Putah Creek surface section, microfossils typical of the G-1 zone were detected directly below the Capay beds and above the normal Cretaceous sequence with zone F′-1 at the top.

[55] Howel Williams, "Geology of the Marysville Buttes, California," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 18, No. 5 (1929), p. 112.

[56] *Ibid.*, pp. 115 and 119.

[57] Charles A. Anderson and R. Dana Russell, "Tertiary Formations of the Northern Sacramento Valley, California," *California Jour. Mines and Geology*, Vol. 35, No. 3 (1939), p. 248. After the discovery of the Cretaceous fossils in Williams' Ione sands, the latter name was changed by some of the geologists working in the area to "Kione" sands.

[58] Harry R. Johnson, "Marysville Buttes (Sutter Buttes) Gas Field," *California Div. Mines Bull. 118*, Pt. 3 (1943), p. 611. The Butte gravel formation overlies the Ione sands and was classified by Williams as the uppermost member of the Meganos in the Marysville Buttes area.

(f) In a well near Willows (T. 20 N., R. 2 W.) some of the Cretaceous fossils indicating, according to F. M. Anderson, the upper part of his Yolo formation,[59] were obtained from the basal beds of the Tehama formation together with two species of mollusks not known in the California sediments older than the upper Miocene, and particularly characteristic of the California Pliocene and Pleistocene.[60]

A ZONE AS A STAGE

The foregoing discussion clearly indicates that the beds of the A zone have a diagnostic organic content and occupy a stratigraphical position between two well defined formations: the Martinez, previously known as the lowest Tertiary in California, and the Moreno the youngest known Cretaceous in California. Therefore, they represent a series deserving to be recognized as a separate stage. Because so far none of the surface sections studied by the writer furnished well preserved and sufficiently complete assemblages typical of the A zone,[61] it is here proposed that this stage be temporarily named the Cheneyan stage after the Cheney Ranch well, in which the A zone was discovered and is best developed.

B ZONE (UPPER CRETACEOUS, UPPER CIERVIAN STAGE)

Zone B is characterized by a faunule composed almost exclusively of arenaceous Foraminifera, including *Gaudryina filiformis* Berthelin.

In the Cheney Ranch well this assemblage appears suddenly within the shale of the typical Moreno lithology below the assemblage characteristic of subzone A-2 and represented by a variety of calcareous Foraminifera. Farther down in the section the B zone arenaceous faunule extends without any perceptible change for about 275 feet, and gives way to the microfauna considered in this paper as diagnostic of the C zone and dominated by *Siphogenerinoides whitei* Church in association with some other calcareous foraminifers.

In the outcrops along the west side of the San Joaquin Valley the B zone is represented by the upper 550 feet of the Moreno at the type locality of the latter, and by the upper 500 feet of the Moreno as mapped by Anderson and Pack near Oil City. In the Escarpado Canyon section the B zone can be correlated with the lower part of the member of the Moreno classified by Payne as the Dos Palos shale. Northwest of the Moreno Gulch the B zone is gradually cut out by the overlapping lower Eocene beds (Fig. 3).

Areal extent of the B zone is confined to a small part of the southwestern part of the San Joaquin Valley, because no lithologic or microfaunal evidence of the zone has been recorded in any of the wells north and east of the line from a point in the vicinity of Panoche Creek to the SE. $\frac{1}{4}$ of T. 15 S., R. 15 E. (southwest of the town of Tranquility), and thence to Sec. 11, T. 17 S., R. 16 E. In all these wells the A zone is found resting directly on the Cretaceous beds of zone C, or C′, or D-1.

[59] Personal communication.

[60] *Cryptomya californica* (Conrad) and *Goniobasis kettlemanensis* Arnold.

[61] One may think that Escarpado Canyon may be one of the most promising localities for the purpose of finding surface equivalent of the A zone.

As mentioned in the description of the A-2 subzone cored by the Cheney Ranch well, this subzone has only two species in common with B zone.[62] On the other hand, all of the species of the B zone extend down into the underlying C zone, and seem to be the last survivors of the species which made their earliest appearance at the beginning of the deposition of the C zone beds and lived through to the end of the deposition of the B zone strata. In view of this the B zone appears to be more closely related to the underlying C zone than to the overlying A zone. Consequently, the top of the B zone may be taken as indicating the top of the Moreno and also the top of the Cretaceous column.

C ZONE (UPPER CRETACEOUS, LOWER CIERVIAN STAGE)

Part of the Upper Cretaceous column referred in this paper to the C zone coincides with abundant occurrence of *Siphogeneroinoides whitei* Church and *Planulina nacatochensis* Cushman. Each of these species is found in places also in the underlying D-1 zone, but only in a restricted number of specimens. In the lower part of the C zone (220–300 feet below its top as recorded in the studied wells, and as much as 1,300 feet below the top of the zone in the Moreno Gulch section) there are also present abundant specimens of *Bulimina prolixa* Cushman & Parker, and near the base of the zone appears one of the species extending down into the underlying D-1 zone.[63]

In the Moreno shale at its type locality, the foraminiferal assemblage of the C zone is found through the Moreno shale, except in the upper 550 feet which, as mentioned, are correlative with the B zone. In the Escarpado Canyon section the age of the C zone should be assigned to the part of the Moreno embracing Payne's Marca shale, Terra Loma shale, and Dosados sand and shale members. Columns in Figure 3 show that the C zone of the same type as in the Moreno Gulch can be traced in the northwesterly direction up to Ortigalito Creek, but in this latter locality the uppermost part of the zone is cut out by the overlapping lower Eocene beds. Still farther northwest, the beds of the C zone change both in their lithologic character (from shale to silty shale), and in their microorganic content, being represented in the Los Banos Creek section by the variant called by the writer the C′ zone.

Study of subsurface sections indicates that the C zone, retaining its typical lithologic and microfaunal characteristics, has in part of the San Joaquin Valley an areal extent only a little wider than that of the B zone. This can be demonstrated by a well in Sec. 12, T. 17 S., R. 16 E. in which the C zone was encountered directly below the Meganos beds. Subsurface columns including the C zone are shown in Figure 9.

C′ ZONE (ECOLOGICAL EQUIVALENT OF C ZONE)

Within the area of the San Joaquin Valley, outside of the comparatively small southwestern part, the Moreno shale of the C zone is represented by silty shales

[62] *Silicosigmoilina californica* Cushman & Church, and *Spiroplectoides clotho* (Grzybowski).

[63] *Siphogenerinoides clarki* Cushman & Campbell var. *costifera* Cushman & Goudkoff.

and silts of the C′ zone. These sediments contain abundant specimens of *Bulimina prolixa* Cushman & Parker in places associated with a few of the long-range Upper Cretaceous species.[64] Near the base of the zone C′ two species are commonly found extending down into the underlying D-1 zone.[65]

The assumption of the equivalency of the C′ zone beds to those of C zone is based on the abundance of *Bulimina prolixa* Cushman & Parker in each zone, and also on the identical stratigraphical position of the beds of the C′ and C zone, as it is demonstrated by the correlation of a well in Sec. 28, T. 12 S., R. 11 E. (about 3 miles southeast of the mouth of Laguna Seca Creek), which penetrated the C zone, with another well about 5 miles farther northwest (Sec. 12, T. 12 S., R. 11 E.), and with a well in Sec. 19, T. 10 S., R. 11 E. (near the town of Los Banos), all of which penetrated the C′ zone.

Along the western border of the San Joaquin Valley the C′ zone can be recognized in the Oat Gulch section between the base of the Garzas sand and the top of the D-1 zone, and in the Ingram Creek section where the zone is represented by the uppermost 400 feet of the Cretaceous strata which are in turn overlain by continental sediments (Fig. 4).

The known subsurface extension of the C′ zone is roughly limited by lines drawn from the town of Oro Loma to a point in the McDonald gas field (Sec. 25, T. 2 N., R. 4 E.), thence through the northwest corner of T. 8 S., R. 11 E. (about 19 miles southeast of Modesto) to Sec. 28, T. 10 S., R. 13 E., and thence back to Oro Loma.

The stratigraphic relations of the C′ zone to the overlying and underlying formations are shown in Figure 8b and Figure 12.

CIERVIAN STAGE (B AND C ZONES)

As stated in the previous discussion, a pronounced break can be observed in the Cheney Ranch well section at the contact between the A and B zones, whereas the B zone is very closely related to the underlying C zone in its lithological character and microfaunal content. On the following pages it is shown that a rather perceptible difference exists in the foraminiferal assemblage found in the C zone as compared with that of the D-1 zone. Therefore, the rank of stage can be assigned to the part of the Cretaceous column embracing the beds of the B and C zones. The stage is well represented in the upper 2,100 feet of the Cretaceous strata exposed in the Moreno Gulch. Yet, as the term Moreno is pre-empted, the writer proposes to name the stage in question the Ciervian stage after Ciervo Hills, because around these Hills there are wells which furnished good foraminiferal material typical of the B and C zones. For instance, continuous sequence of the beds of the B and C zones was cored by the Western Gulf Oil Company's Lillis-Welch well No. 1 (Sec. 26, T. 15 S., R. 12 E.) between depths of 4,016 feet and 4,899 feet.

[64] *Epistomina caracolla* (Roemer), and *Robulus macrodiscus* (Reuss).

[65] *Planulina nacatochensis* Cushman and *Siphogenerinoides clarki* Cushman & Campbell.

The foraminiferal faunule characteristic of the C′ zone can be found in core samples taken from the Amerada Petroleum Corporation's Carano well No. 1 (Sec. 19, T. 10 S., R. 11 E.) between depths of 6,518 feet and 7,163 feet.

D-1 ZONE (UPPER CRETACEOUS, UPPER INGRAMIAN STAGE)

This zone is characterized by several foraminiferal species[66] which do not occur in any other foraminiferal zone (except in A-2 and A′-2 where they are considered as redeposited). In some places associated with these species are a few of those found in the lower part of the C (or C′) zone,[67] and commonly there are also found some of the microfossils typical of zone D-2.[68]

In the outcrops along the west side of the San Joaquin Valley between Alcalde Hills and Ortigalito Creek, the D-1 zone corresponds roughly with the disputed part (up to more than 750 feet thick) referred to the Moreno by some geologists and to the Panoche by others.[69] The lack of agreement in placing the Moreno-Panoche contact can be easily explained by the chart of Figure 3, which shows that this contact, if based on the foraminiferal content of the Moreno and the Panoche at their type localities, falls in a different part of the Moreno, as mapped by R. Anderson and Pack, in all the localities illustrated in Figure 3, except in Escarpado Canyon. In other words, the diversity of views regarding the boundary between the two formations may be due to the extreme lateral lithologic variations of the corresponding part of the column, and also, probably, due to the lenticular character of most of the sandy beds which usually serve as a guide in field mapping.

Also, only on the lithologic basis, the thick body of shale in the area northwest of Corral Hollow Creek (T. 3 S., R. 5 E.) was mapped by R. Anderson and Pack as the Moreno shale. It actually represents (except for a small uppermost part) shaly facies of the Panoche zones D-1, D-2, and E, and its base is correlative with the horizon found in the Moreno Gulch 5,500 feet below the base of the Moreno at the type locality of the latter.

Study of subsurface sections indicates that the D-1 zone is developed throughout the San Joaquin Valley largely in the form of silty shales or silts with minor amounts of sand. In every one of the studied wells this zone is found conformably underlain by the beds of the D-2 zone, whereas the strata overlying the D-1 zone belong to the C or C′ zone in the southwestern part of the valley, or to different horizons of the A zone (Figs. 8b, 9, 11, and 12).

[66] *Bulimina petroleana* Cushman & Hedberg, *Cibicides* cf. *coonensis* (W. Berry), and *Eponides ingramensis* Cushman & Goudkoff.

[67] *Bulimina prolixa* Cushman & Parker, *Planulina nacatochensis* Cushman, *Siphogenerinoides clarki* Cushman & Campbell v. *costifera* Cushman & Goudkoff, and *Siphogenerinoides clarki* Cushman & Campbell.

[68] *Gaudryina navarroana* Cushman v. *crassaformis* Cushman & Campbell, *Gyroidina depressa* (Alth), *Gyroidina globosa* (Hagenow), *Globotruncana arca* (Cushman), and *Nodosaria spinifera* Cushman & Campbell.

[69] Hubert G. Schenck "*Acila princeps*, a New Upper Cretaceous Pelecypod from California," *Jour. Paleon.*, Vol. 17, No. 1 (1943), p. 62.

Northwest of the San Joaquin Valley the D-1 zone can be traced into the Sacramento Valley as far as T. 6 N., R. 2 E., T. 6 N., R. 3 E., and T. 9 N., R. 1 E. In the wells nearer the east side of the Sacramento Valley in T. 10 N., R. 4 E., and T. 1 N., R. 8 E. (Fig. 10), the presence of the D-1 zone has been only tentatively identified on the basis of a meager microfauna in the beds overlying the E zone in these wells. Particularly questionable is the identification of the D-1 zone in the well in T. 1 N., R. 8 E., in which the microfauna just mentioned has been found in very coarsely grained sediments, and in view of this may be considered as redeposited.

D-2 ZONE (UPPER CRETACEOUS, LOWER INGRAMIAN STAGE)

The D-2 zone, as here defined, can be recognized by the presence of *Bolivina incrassata* Reuss accompanied by other Foraminifera species which make their first appearance below the D-1 zone.

In the Alcalde Hills outcrops the microfauna typical of the D-2 zone has been detected in the upper half of J. Q. Anderson's Ragged Valley shale.[70] In the area between Oil City and Laguna Seca creeks the beds of the D-2 zone were mapped by R. Anderson and Pack as the upper part of the Panoche formation composed of sandstones interbedded with a few layers of shale or silty and sandy shales. The same zone is found in the sections exposed in Ortigalito and Los Banos creeks and in Oat Gulch. It is composed there of the series of shales and silty shales with minor amounts of sand and silt referred by R. Anderson and Pack to the upper part of the Panoche, or to the middle of the Moreno (Fig. 3 and Fig. 4). Still farther northwest, up to the north side of Mt. Diablo, zone D-2 occupies a middle part of the thick body of shale mapped by R. Anderson and Pack, and by J. A. Taff[71] as the Moreno formation.

Under the surface the D-2 zone spreads over the western and middle parts of the San Joaquin Valley, the eastern limit of the areal extent of the zone being roughly along a line from Stockton to Riverdale. The most northerly wells in which the D-2 zone has been recorded are in T. 9 N., R. 1 E., T. 6 N., R. 2 E., and T. 6 N., R. 3 E.

It is interesting to note that in the subsurface sections the D-2 zone shows much less lateral lithologic variations than in the outcrops. As shown in Figs. 7b, 8a, 8b, 9, 11, and 12, the zone is nearly everywhere represented by sandy beds containing only a few shales or sandy shales.[72] The only exception is the well south of Stockton (T. 1 S., R. 6 E., Figs. 8a and 12) in which the zone is made up completely of shales and silty shales; this lithologic character is particularly striking because in a well 7 miles southwest (T. 1 S., R. 6 E., near the town of Tracy the zone is very sandy.

[70] J. Q. Anderson, talk before the Pacific Section, Soc. Econ. Paleon. and Min. at Bakersfield, June 6, 1941.

[71] J. A. Taff, "Geology of Mount Diablo and Vicinity," *Bull. Geol. Soc. America*, Vol. 46 (July, 1935), pp. 1079–1100.

[72] In the wells between Chowchilla and Riverdale the thick body of sands within the D-2 zone is locally known as the "Big Panoche sand."

INGRAMIAN STAGE (D-1 AND D-2 ZONES)

The thickest and most representative section of the D-1 zone was penetrated by the Union Oil Company's Tracy L. & W. well No. 1 (Sec. 14, T. 3 S., R. 6 E.) in which the top of the zone was encountered at the depth of 3,543 feet and was cored to a depth of about 5,100 feet. As the best type of zone D-2, the writer considers the Amerada Petroleum Corporation's F. D. L. well No. 1 (Sec. 15, T. 2 S., R. 5 E.) between the depths of 3,871 feet and 5,715 feet.

A few good foraminiferal samples collected from the outcrops in Ingram Creek suggest that this section may serve as the surface type of the D-1 and D-2 zones, and is probably similar to the beds of these zones in the wells previously named. For this reason the name Ingramian is proposed for the part of the column embracing the two zones. The term upper Ingramian (D-1 zone) may be applied to that part of the Ingram section from a horizon about 400 feet below the top of the Cretaceous section and down to the first occurrence of *Bolivina incrassata* Reuss (recorded in a sample taken 2,370 feet below the top of the Cretaceous), and lower Ingramian (D-2 zone) may be used for the underlying strata from the first appearance of *Bolivina incrassata* down to the highest stratigraphic occurrence of *Anomalina henbesti* Plummer which marks the top of the E zone (recorded by the writer in a sample taken 3,407 feet below the top of the Cretaceous in the Ingram Creek section).

E ZONE (UPPER CRETACEOUS, TRACIAN STAGE)

Below the D-2 zone is a zone characterized by the appearance of *Anomalina henbesti* Plummer and a number of other species taken to be diagnostic of the E zone.

This zone is correlative with the lower part of the J. Q. Anderson's Ragged Valley shale, and with the second (from the top) shale member of the Panoche, as described by Anderson and Pack.[73] In the outcrops along the Los Banos Creek and farther northwest the foraminiferal faunule of the E zone is found in the lower part of the body of shales mapped by Anderson and Pack as the Moreno. On the north side of Mount Diablo the microfauna of the E zone has been identified in the basal beds of the shale directly above the Panoche of Taff[74] (Fig. 4).

In subsurface sections the E zone is largely represented by shales or silty shales (Figs. 7b, 8a, 8b, 9, 10, and 12). A body of sands appears in the lower part of the zone only in some of the wells in the southeast part of the San Joaquin Valley (column in T. 17 S., R. 14 E., Fig. 8b, and columns in T. 15 S., R. 15 E., and T. 17 S., R. 19 E., Fig. 9). The only well in which the E zone is rather sandy throughout is that in T. 6. N., R. 2 E. (Fig. 7b).

In the outcrops along the west side of the San Joaquin Valley the E zone is underlain with apparent conformity by the F-1 zone. The same stratigraphic position has been recorded in a well about 6 miles south of Vacaville (T. 5 N., R. 1 W.).

[73] Robert Anderson and R. W. Pack, *op. cit.*, p. 41.

[74] J. A. Taff, *op. cit.*

Data from wells nearer the east side of the San Joaquin Valley suggest that the beds of the E zone were laid down without any hiatus over the strata here classified as the F′-1 zone. The contact between the two zones, however, can be easily located by disappearance of the most typical E zone Foraminifera and by appearance of the microfossils considered to be characteristic of the F′-1 zone. The only exception to this rule is a well in T. 7 N., R. 6 E. (southeast of Sacramento) which cored about 300 feet of beds containing one of the most typical E zone species (*Anomalina henbesti* Plummer) side by side with the species typical of the F′-1 zone (*Marginulina curvisepta* Cushman & Goudkoff). Just above the beds with the mixed E and F′-1 Foraminifera, the well penetrated 50 feet of claystone very rich in glauconite, which might indicate a break in deposition.

As compared with the overlying D-2 zone, the beds of the E zone extend farther toward the eastern border of the Great Valley. This is demonstrated by wells north and south of Sacramento (T. 10 N., R. 4 E., and T. 7 N., R. 6 E.), and also in the Lodi Community area (T. 4 N., R. 6 E., and T. 4 N., R. 7 E.), in which wells the E zone is found directly below the beds tentatively referred to the A zone, whereas the higher Cretaceous zones, including D-2, are missing (Fig. 10). With less certainty the writer has assigned to the E zone the beds encountered directly below the continental sediments in the well in T. 2 S., R. 10 E. (about 12 miles northeast of Modesto).

The northern boundary of the areal extension of the E zone can be defined approximately by a line from a point between Vacaville and the mouth of Putah Creek toward the northwest corner of T. 10 N., R. 4 E.

E′ ZONE (ECOLOGICAL VARIANT OF ZONE E)

In the northern half of the Sacramento Valley, the microfauna of the E zone gives way to a comparatively meager foraminiferal assemblage including a large form of *Dentalina megapolitana* Reuss[75] and fairly common specimens of *Haplophragmoides colusaensis* Cushman & Goudkoff. The beds containing this assemblage are called in this paper the E′ zone. They are assumed to represent the stratigraphical equivalent of the beds of the E zone because, just like the latter, they seem to have been laid down without any interruption right after the deposition of the F′-1 zone. The general aspect of the E′ microfauna suggests that it is a shallower-water type than the faunule of the E zone.

Silty clays and mudstones referred to the E′ zone form, in the writer's opinion, the highest Cretaceous strata in the northwestern part of the Sacramento Valley basin. They are overlain either by the sands tentatively assigned to the A zone, or by continental sediments of the Tehama formation (Figs. 6b, 10, and 11).

In the surface outcrops studied by the writer no beds corresponding with the E′ zone have been found. Very likely they are cut out by the overlap of the Eocene Capay beds or of the Tehama formation over the Forbes formation (Fig. 5).

[75] Pictured in *Contrib. Cushman Lab. Foraminiferal Research*, Vol. 20, Pt. 3 (1944), Pl. 9, Fig. 11.

TRACIAN STAGE

In all of the studied surface sections the microfauna of the E zone has been found in only a few scattered samples. On the other hand, nearly continuous coring by the Amerada Petroleum Corporation's F. D. L. well No. 1 (Sec. 15, T. 2 S., R. 5 E.), near the town of Tracy, has furnished very good foraminiferal material in samples taken from the interval between 5,715 feet and 6,900 feet. For this reason, the writer proposes the *Tracian* stage as a temporary name for the stage of the E zone.

F-1 ZONE (UPPER CRETACEOUS, UPPER WELDONIAN STAGE)

In the sections exposed along the west side of the San Joaquin Valley below the beds of the E zone is a foraminiferal assemblage represented largely by arenaceous species indicating deep or cool waters.[76] This assemblage characterizes, the F-1 zone and occurs in shale streaks of the series corresponding with: the upper part of the Joaquin Ridge sandstone of J. Q. Anderson; the upper part of the Panoche formation as mapped by Anderson and Pack in the Los Banos Creek area and in the area farther northwest; and the upper part of the Panoche of Taff in the Marsh Creek section (Figs. 3 and 4).

The known subsurface extension of the F-1 zone is confined to a narrow strip along the west side of the San Joaquin Valley. The only wells in which the zone was encountered are: one southwest of Coalinga (T. 21 S., R. 14 E.), and six in the Tracy district (T. 2 S., R. 5 E.; T. 3 S., R. 3 E.; T. 3 S., R. 4 E.; and T. 4 S., R. 5 E.). The most northerly record of the F-1 zone is in the well south of Vacaville, in T. 5 N., R. 1 W. As one can see from the charts (Figs. 7b and 8a), the subsurface sections of the F-1 zone are much more shaly then its surface equivalents.

F′-1 ZONE (ECOLOGICAL VARIANT OF F-1 ZONE)

In wells nearer the east border of the San Joaquin Valley, the beds of the F-1 zone are represented, in the writer's belief, by its shallower and warmer facies here designated F′-1. The microfauna of this F′-1 zone is largely made up of calcareous Foraminifera of the subfamily Nodosarinae.[77] The stratigraphic equivalence of the F′-1 faunule to that of the F-1 is suggested by identical stratigraphic position (below the E zone) supported by the presence of a few species common to both facies.[78]

From the east side of the San Joaquin Valley the F′-1 zone can be traced into the Sacramento basin where it has been encountered by all of the studied wells except those drilled in the Rumsey Hills and in the adjacent area (the well in

[76] *Ammodiscoides turbinatus* Cushman, *Bathysiphon taurinensis* Sacco, *Cribrostomoides cretacea* Cushman & Goudkoff, *Haplophragmoides eggeri* Cushman var. *minuta* Cushman & Goudkoff, *Nodellum* sp., etc.

[77] Species of *Chrysalogonium*, *Dentalina*, *Frondicularia*, *Nodosaria*, and several species of *Marginulina* including the most typical of the zone *Marginulina curvisepta* Cushman & Goudkoff.

[78] *Gaudryina rudista* Sandidge v. *directa* Cushman & Goudkoff, and *Globotruncana canaliculata* (Reuss).

T. 13 N., R. 3 W.). In the outcrops along the west side of the Sacramento Valley the zone is represented by the Forbes formation in the Putah Creek section as described by Kirby (Fig. 5).

Lithologically the F′-1 zone is composed prevailingly of fine-grained sediments, claystone, and silty claystone, with minor amounts of sand. Some of the sand, as in a well in T. 10 S., R. 14 E., may be contintental in origin.

In wells nearer the eastern border of the Great Valley the F′-1 zone rests unconformably on the basement complex (see columns in T. 14 N., R. 5 E., Fig. 7a; T. 7 N., R. 6 E., Fig. 7b; T. 4 N., R. 6 E., Fig. 10; and T. 10 S., R. 14 E., Fig. 8b), or on pre-Cretaceous sediments (T. 17 S., R. 19 E.). In wells in the middle of the Sacramento Valley and in the outcrops along its western side the zone is conformably underlain by earlier Cretaceous strata.

The well southeast of Marysville, in T. 14 N., R. 5 E. (Fig. 7a), in which the F′-1 zone was encountered directly below the Eocene Capay beds, suggests that this zone extends eastward somewhat farther than the E′ zone.

F-2 ZONE (UPPER CRETACEOUS, LOWER WELDONIAN STAGE)

The foraminiferal content of the F-2 zone includes a few species which seem to be confined to this zone,[79] and a few of those typical of the underlying G-1 and G-2 zones;[80] there are also present several of the species extending down from the overlying zone

The zone is best developed in the outcrops on the west side of the Sacramento Valley, where it corresponds with that part of the column embracing the basal beds of the Forbes formation, the whole thickness of the Guinda, and the upper part of the Funks, as these members of the Chico series are shown by Kirby in the Putah Creek section. To the same zone may belong, in the writer's opinion, the upper 2,500 feet of the Cretaceous beds exposed on the east flank of the Rumsey Hills. Unfortunately, samples taken from these beds are either entirely barren of microfossils or contain only a few Foraminifera of no correlative value; thus the age of the F-2 zone has been only tentatively assigned to these strata on the basis of their stratigraphic position directly above a very well defined G-1 zone.

Typical F-2 Foraminifera have been detected also in the Marsh Creek and Ingram Creek sections (Fig. 4), as well as in samples from the Escarpado Canyon, the Moreno Gulch, and the Ortigalito Creek sections (Fig. 3). In other sections shown in Figure 3 (Alcalde Hills and Laguna Seca) the beds barren of any diagnostic fossils but occupying a stratigraphic position below the strata with distinct F-1 Foraminifera and above those with the microfossils typical of the G-1 zone have been correlated with the F-2 zone.

[79] *Bathysiphon perampla* Cushman & Goudkoff, and large flat form of *Trochammina* sp. with indistinct sutures.

[80] *Gaudryina retusa* Cushman and *Stensioina excolata* (Cushman).

The wells which furnished the F-2 faunule are near the west side of the Great Valley: one near Willows (T. 20 N., R. 2 W.), one near Colusa (T. 16 N., R. 1 W.), and four in the Tracy district. (T. 2 S., R. 5 E.; T. 3 S., R. 3 E.; T. 3 S., R. 4 E.; and T. 4 S., R. 5 E.).

The charts illustrating the Cretaceous sections penetrated by some of these wells (Figs. 6a, 7a, and 8a) indicate that the F-2 zone pinches out not far east. Comparison of these charts with those showing the surface sections (Figs. 4 and 5) shows that the F-2 zone in the subsurface sections is much more shaly than in its exposures along the west side of the Great Valley.

WELDONIAN STAGE (F-1, F′-1, AND F-2 ZONES)

Since the areal extension of the F′-1 zone is much greater than that of its ecological variant F-1, and since both the F′-1 and F-2 zones are well represented in the outcrops along Weldon Canyon, the term Weldonian seems suitable for the stage comprising both zones. Thus, it is proposed to call the F′-1 (and F-1) zone the upper Weldonian, and the F-2 zone the lower Weldonian.

The best foraminiferal material characteristic of the F-1 zone has been obtained from the Amerada Petroleum Corporation's F. D. L. well No. 1 (Sec. 15, T. 2 S., R. 5 E.) between depths of 6,900 feet and 8,900 feet. A good faunule the of F-2 zone has been found in samples from the same well between the depths of 8,900 feet and 9,431 feet. Zone F′-1 is well developed is the Ohio Oil Company's Willard No. 1A (Sec. 18, T. 20 N., R. 2 W.) between depths of 3,231 feet and 5,250 feet.

G-1 ZONE (UPPER CRETACEOUS, UPPER CACHENIAN STAGE)

The foraminiferal assemblage of the G-1 zone may be regarded as the richest and most diversified in the whole Upper Cretaceous column of the Great Valley. It includes species not occurring in the overlying zones, and is particularly characterized by *Planularia tricarinella* (Reuss). The Foraminifera of this zone are commonly accompanied by more or less abundant Radiolaria.

In outcrops along the west side of the San Joaquin Valley the G-1 zone is represented by the Alcalde shale, as classified by J. Q. Anderson in the Alcalde Hills section,[81] and by the series of shales or silty shales with minor amounts of sands which compose the lowest 1,500 feet of the section sampled in the Escarpado Canyon, and by the part of the Moreno Gulch section between the horizons 7,670 and 10,165 feet below the top of the type Moreno. From the same series come a few samples with good G-1 microfauna collected in the Laguna Seca, Ortigalito, and Los Banos Creek surface sections (Fig. 3). Farther northwest the typical G-1 Foraminifera have been detected in the exposures along Marsh Creek mapped by Taff as the Chico formation (Fig. 4).

[81] This shale was described by R. Anderson and Pack (*op. cit.*, pp. 26 and 40) as "black clay shale" forming the lower member of the Joaquin Ridge.

Along the west side of the Sacramento Valley, correlative with the G-1 zone are: the lower part of the Funks formation in the Putah Creek section as defined by Kirby; the basal 475 feet of beds exposed on the crest of the Rumsey Hills (basal beds of Kirby's type Forbes); and members VI, V, and the upper part of member IV of the Redding Cretaceous strata as described by Popenoe (Fig. 5). To the G-1 zone also belongs the Funks formation as shown by Kirby in the sections of Cache Creek (T. 12 N., R. 4 W.) and Salt Creek (T. 15 N., R. 4 W.).

Because of the deep stratigraphic position of the G-1 zone beds in the Upper Cretaceous column exposed along the west side of the San Joaquin Valley, these beds were reached by only a few wells either within the Cretaceous outcrops (like the California North. Petroleum well No. 19 in Sec. 2, T. 21 S., R. 14 E., and the Shell Oil Company's Nissen No. 1 in Sec. 7, T. 2 S., R. 14 E.), or in the areas where the Cretaceous strata are thinly overlain by younger formations (well west and southwest of Tracy in T. 3 N., R. 4 E.; T. 3 S., R. 3 E.; and T. 4 S., R. 5 E.). In the Sacramento Valley, where the latest Upper Cretaceous beds are missing, the G-1 zone was found in wells near the middle of the valley as follows: at the town of Corning (T. 24 N., R. 3 W.), east of Corning (T. 23 N., R. 1 E.), northeast and east of Willows (T. 21 N., R. 1 W.; T. 21 N., R. 1 E.; and T. 20 N., R. 1 E.), and in one of the wells in the Buttes gas field (Sec. 1, T. 15 N., R. 1 E.).

The eastern border of the subsurface extension of the G-1 zone is not known beyond the fact that the zone is missing in wells along a line from T. 14 N., R. 5 E. (southeast of Marysville) toward T. 1 N., R. 8 E. (east of Stockton), and also missing in the wells on a line connecting T. 10 S., R. 14 E. (west of Chowchilla) with T. 17 S., R. 19 E. (at Riverdale). In all these wells the G-1 zone is cut out by the unconformity separating the beds of the F′-1 zone from the basement rocks or pre-Cretaceous sediments.

Charts illustrating some of the wells in which the G-1 zone was cored (Figs. 6b, 8a, and 10) show a considerable thinning of the zone toward the central part of the Sacramento Valley. From the thickness of more than 2,700 feet in T. 24 N., R. 2 W., the zone thins to about 2,200 feet in T. 21 N., R. 1 W., to 1,350 feet in T. 21 N., R. 1 E., and to only 1,200 feet in T. 20 N., R. 1 E. The charts also show that the zone is prevalently composed of shales or silty shales with sandy beds appearing only in the basal part of the zone (Fig. 10).

It may be added that the microfaunal content of core samples taken from the G-1 zone in the most easterly wells is more meager as compared with the abundant foraminiferal faunules found in the westerly wells and in the corresponding surface exposures.

G-2 ZONE (UPPER CRETACEOUS, LOWER CACHENIAN STAGE)

Judged by present knowledge, the micro-organic content of the G-2 zone differs from that of the G-1 zone only in the common and persistent presence of *Cibicides stephensoni* Cushman and in less common occurrence of *Vaginulina kochii* Roemer.

The G-2 zone is best represented in the part of the column exposed along the west side of the Sacramento Valley embracing the Sites formation and the upper part of the Yolo formation as described by Kirby in the Putah Creek and the Cache Creek sections. In the outcrops on the west side of the San Joaquin Valley, the microfauna containing *Cibicides stephensoni* has been found in samples in Marsh Creek 6,800 feet and 7,600 feet below the top of Taff's Chico formation, and in the beds exposed in Hospital Creek about 10,000 feet below the top of the Moreno as mapped by R. Anderson and Pack.

The microfauna suggesting the G-2 zone has been recorded in the part of the Moreno Gulch section between horizons 10,170 feet and 12,000 feet below the top of the type Moreno. Also, the writer believes, the upper Waltham shale, as defined by J. Q. Anderson, may belong to the G-2 zone.

Under the surface the G-2 zone was encountered by two of the wells northeast and east of Willows (T. 21 N., R. 1 E., and T. 20 N., R. 1 E.), by three wells in the Rumsey Hills (T. 12 N., R. 3 W.), and by two wells west and southwest of Tracy (T. 2 S., R. 3 E., and T. 3 S., R. 3 E.).

In the most easterly of the wells which penetrated the G-2 zone (for example, in T. 20 N., R. 1 E., Fig. 10) the beds of this zone rest unconformably on the basement rocks. In wells nearer the west side of the Great Valley the zone overlies with apparent conformity the strata here classified as the H zone.

Subsurface eastward extension of the G-2 zone probably does not reach the eastern border of the G-1 zone. This is suggested by the fact that in Chico Creek (T. 23 N., R. 3 E.) the beds correlative with the G-1 zone are unconformably underlain by the basement rocks.

CACHENIAN STAGE

Because most, if not all, of the Foraminifera species present in the G-1 zone extend down into the G-2 zone, it seems appropriate to consider the two zones as parts of one stage. And since both of them are well developed in the surface section of Cache Creek (T. 12 N., R. 4 W.), it is proposed to name the beds of the G-1 zone the upper Cachenian stage, and those of the G-2 zone the lower Cachenian stage.

H ZONE (DELEVANIAN STAGE)

To this zone the writer has assigned the lowest part of the Upper Cretaceous column tentatively correlated with the Pioneer group of F. M. Anderson, with the lower part of the Yolo and the whole Venado formations of Kirby. To the same zone belong the lowest 14,000 feet of the Moreno Gulch section, the lowest 5,425 feet of beds exposed in Ingram Creek, and at least 1,450 feet composing the lowest beds in the Hospital Creek surface section. It is possible that to the H zone should also be referred the members into which J. Q. Anderson has divided the lowest part of the Panoche in the Alcalde Hills (Juniper Ridge sandstone, lower Waltham shale, Long Canyon sandstone, and Curry Mountain shale).

The subsurface equivalent of the H zone the writer believes is the series of

bluish gray silty shale (with minor amount of sand) cored below the beds of the G-2 zone by the wells in the Rumsey Hills and by a well west of Tracy, in T. 2 S., R. 3 E.

The surface and subsurface samples taken from the H zone beds have furnished only a meager fauna of poorly preserved and indeterminate species of arenaceous Foraminifera, here and there associated with limonitized radiolarian tests. In some of the samples these tests are the only organic remains.

The fact that in a well in T. 20 N., R. 1 E., the beds of the G-2 zone rest directly on the basement rocks is evidence that the strata of the H zone do not extend as far east as those of the overlying zone.

DELEVANIAN STAGE

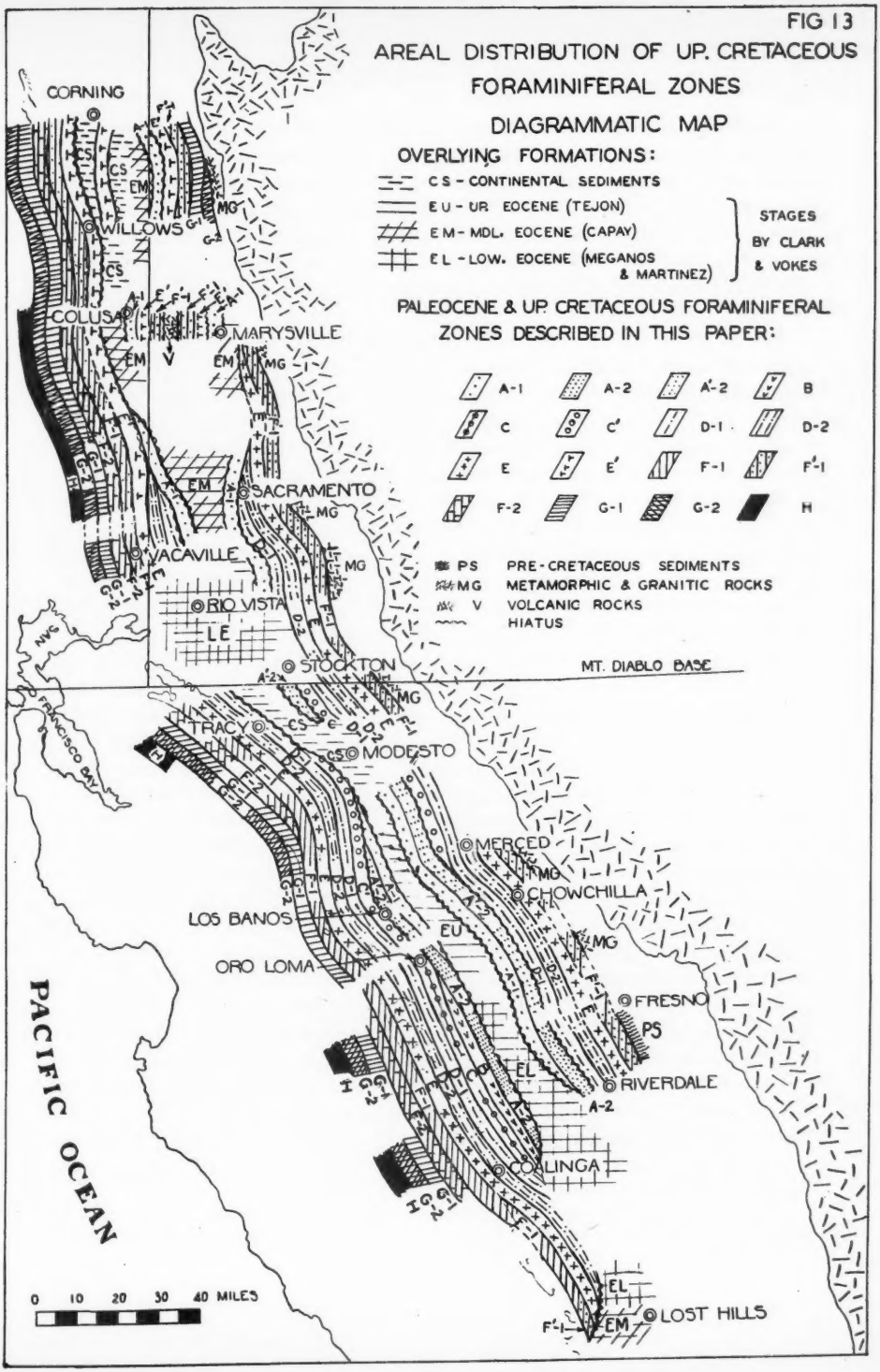
The beds of the H zone attain a thickness of several thousand feet and are marked by similar lithologic character and micro-organic content in the surface sections along the Great Valley all the way from the Moreno Gulch almost up the northern end of the valley. Thus, they most certainly represent a well defined stage of the Upper Cretaceous. The section of the H zone beds is well exposed along Funks Creek (T. 17 N., R. 4 W.) where it includes the lowest 150 feet of Kirby's Yolo formation and the whole thickness of Kirby's Venado. Yet, as the term Funks is pre-empted, the writer proposes to name the stage the Delevanian stage after the town of Delevan near Funks Creek, Sec. 23, T. 17 N., R. 3 W.

GENERAL AREAL RELATIONS OF ZONES

A diagrammatic map and a series of diagrammatic cross sections shown in Figures 13 and 14 summarize the writer's views on the relative areal extent and stratigraphical relations of the foraminiferal zones previously described. Analysis of these illustrations brings out several points important for restoration of the Upper Cretaceous paleogeography.

The first and, probably, the most important of these points is the disappearance of the Upper Cretaceous zones along the Great Valley from the southeast to the northwest. Indeed, Figure 13 shows that the shaly facies of the Ciervian stage (B and C zones) is confined to the most southwesterly part of the valley between Coalinga and Oro Loma. Farther northwest the upper Ciervian beds (zone B) completely disappear, and the lower Ciervian shales give way to the silty facies of the same stage (zone C′). The farthest northwestern record of the C′ zone is in a well within the McDonald gas field (T. 2 N., R. 4 E.). Farther northwest no representatives of the C zone are found, and the Upper Cretaceous sediments begin with the Ingramian stage (D-1 zone). The Ingramian stage, in turn, disappears northwest of a line drawn approximately from Vacaville to Marysville. This line divides the Tracian and upper Weldonian beds of the E and F-1 zones on the south from their shallow-water equivalents, the E′ and F′-1 zones, on the north.

FIG 13


AREAL DISTRIBUTION OF UP. CRETACEOUS FORAMINIFERAL ZONES
DIAGRAMMATIC MAP
OVERLYING FORMATIONS:
CS - CONTINENTAL SEDIMENTS
EU - UP. EOCENE (TEJON)
EM - MDL. EOCENE (CAPAY)
EL - LOW. EOCENE (MEGANOS & MARTINEZ)
STAGES BY CLARK & VOKES
PALEOCENE & UP. CRETACEOUS FORAMINIFERAL ZONES DESCRIBED IN THIS PAPER:
A-1 A-2 A'-2 B
C C' D-1 D-2
E E' F-1 F'-1
F-2 G-1 G-2 H
PS PRE-CRETACEOUS SEDIMENTS
MG METAMORPHIC & GRANITIC ROCKS
V VOLCANIC ROCKS
HIATUS
MT. DIABLO BASE
CORNING
WILLOWS
COLUSA
MARYSVILLE
SACRAMENTO
VACAVILLE
RIO VISTA
STOCKTON
TRACY
MODESTO
MERCED
CHOWCHILLA
LOS BANOS
ORO LOMA
FRESNO
RIVERDALE
COALINGA
LOST HILLS
PACIFIC OCEAN
SAN FRANCISCO BAY
0 10 20 30 40 MILES

Another outstanding fact is that a complete sequence of the lower stages of the Upper Cretaceous (lower Weldonian or F-2 zone, upper and lower Cachenian or G-1 and G-2 zones, and Delevanian or H zone) is found all along the west side of the valley, whereas on the east two or more of these stages are missing: as previously mentioned, the G-1 zone is resting unconformably on the basement complex in the Chico Creek outcrops, and throughout the distance from Marysville to Riverdale the oldest known Cretaceous beds belong to the F′-1 facies of the upper Weldonian.

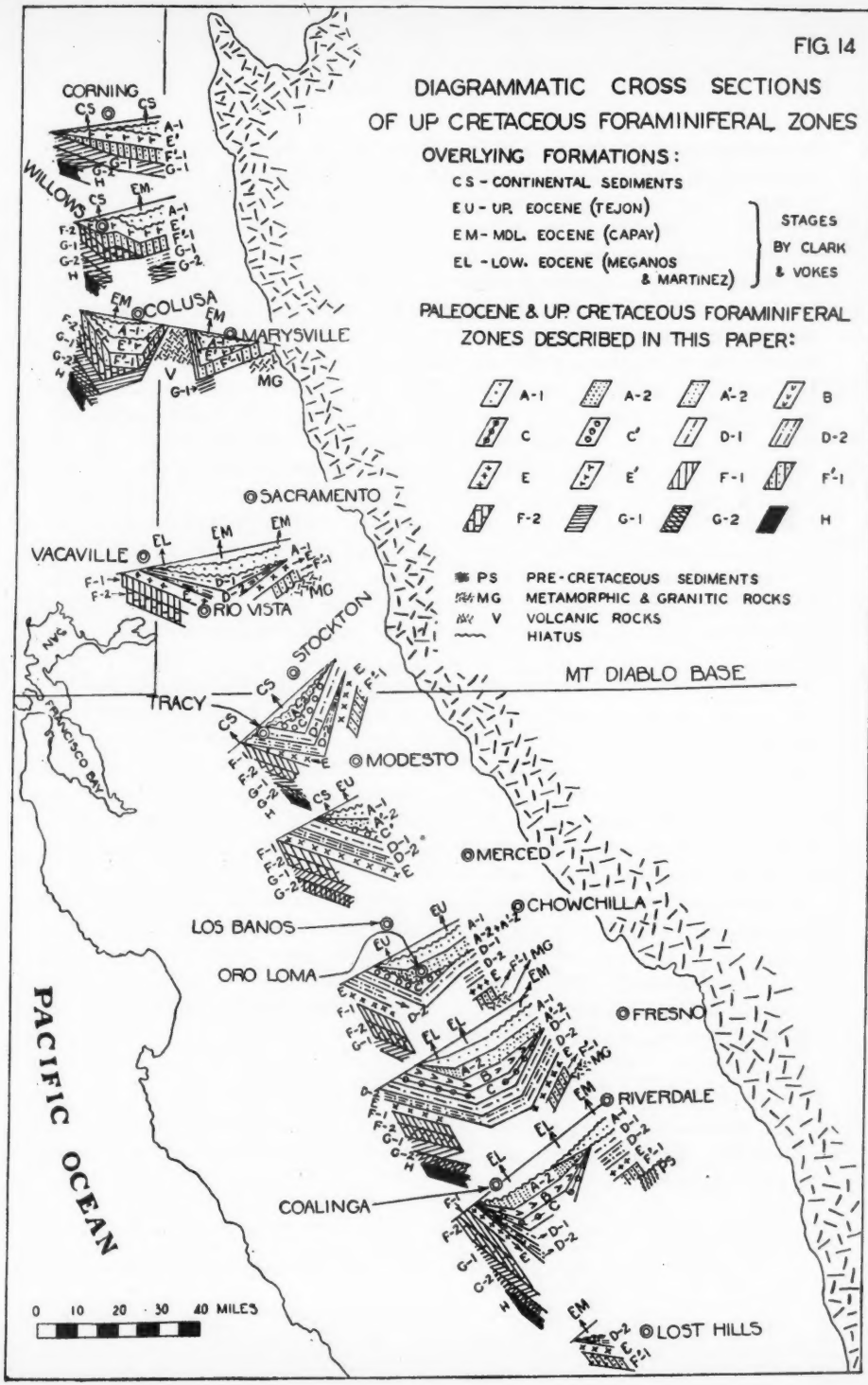
Figure 13 also shows that none of the Cretaceous zones goes across the area around the town of Rio Vista. This area undoubtedly forms a rather deep depression. Even the deepest well (Amerada Petroleum Corporation's Happe No. 1, Sec. 27, T. 4 N., R. 2 E., total depth 7,029 feet) did not reach the Cretaceous sediments although it went through more than 4,750 feet of the Lower Tertiary beds. The depression probably extends westward into the vicinity of Suisun Bay, because wells as far west as T. 4 N., R. 1 W., were still in the Martinez strata at the depth of 6,000 feet. While it is true that in the Potrero Hills gas field one of the wells cored a considerable thickness of the Cretaceous lower Weldonian beds (F-2 zone) from a depth of about 3,575 feet directly below the shale of the lower Martinez age, the Potrero Hills structure is badly distorted by numerous post-Eocene faults, and thus the present position of the strata penetrated by the Potrero Hills wells can not be considered normal. On the northern, eastern, and southern sides, the Rio Vista depression can be marked by the wells which reached the Cretaceous between depths of 6,400 and 6,900 feet in the following locations: Sec. 15, T. 7 N., R. 3 E.; Sec. 36, T. 5 N., R. 5 E.; and Sec. 24, T. 1 N., R. 5 E. It may be added that in the great development of the Eocene sediments the Rio Vista depression has the stratigraphical features common to the north side of Mount Diablo, where there are nearly 7,800 feet of the Tertiary beds embracing all of the Eocene stages of Clark and Vokes[82] from the Tejon down to and including the Martinez.[83] The map of Figure 13 suggests that just south of the Rio Vista depression and across the northern portion of the San Joaquin Valley, some kind of a barrier or an isthmus must have been present during Eocene time. Such an assumption is prompted by the fact that in the outcrops northwest and southwest of Tracy, and also in wells south and southeast of Stockton (Sec. 8, T. 1 S., R. 6 E., and Sec. 22, T. 1 S., R. 7 E.) either the upper Ingramian (zone D-1) or the lower Chenyan (zone A′-2) strata are directly overlain by continental sediments.

The writer desires to emphasize several features indicated in the diagrammatic cross sections of Figure 14: (1) the general trend of the Great Valley geosyncline with its axis rather close to and parallel with the west side of the valley; (2) a distinct plunge southeast both in the Sacramento and San Joaquin parts of the

[82] B. L. Clark and H. E. Vokes, "Summary of Marine Eocene Sequence of Western North America," *Bull. Geol. Soc. America*, Vol. 47 (June, 1936), p. 856.

[83] B. L. Clark and A. O. Woodford, "The Geology and Paleontology of the Type Section of the Martinez Formation (Lower Eocene) of California," *Univ. California Pub., Dept. Geol. Sci., Bull. 17* (1927), pp. 63–142.

FIG. 14


DIAGRAMMATIC CROSS SECTIONS
OF UP CRETACEOUS FORAMINIFERAL ZONES
OVERLYING FORMATIONS:
CS - CONTINENTAL SEDIMENTS
EU - UP. EOCENE (TEJON)
EM - MDL. EOCENE (CAPAY)
EL - LOW. EOCENE (MEGANOS & MARTINEZ)
STAGES BY CLARK & VOKES
PALEOCENE & UP. CRETACEOUS FORAMINIFERAL ZONES DESCRIBED IN THIS PAPER:
A-1 A-2 A'-2 B
C C' D-1 D-2
E E' F-1 F'-1
F-2 G-1 G-2 H
PS PRE-CRETACEOUS SEDIMENTS
MG METAMORPHIC & GRANITIC ROCKS
V VOLCANIC ROCKS
HIATUS
MT DIABLO BASE
CORNING
WILLOWS
COLUSA
MARYSVILLE
SACRAMENTO
VACAVILLE
RIO VISTA
STOCKTON
TRACY
MODESTO
MERCED
CHOWCHILLA
LOS BANOS
ORO LOMA
FRESNO
RIVERDALE
COALINGA
LOST HILLS
PACIFIC OCEAN
SAN FRANCISCO BAY
0 10 20 30 40 MILES

geosyncline (note the depth to the uppermost of the shown foraminiferal zones increases from the Corning cross section to that of the Vacaville-Sacramento, and from the Tracy-Stockton cross section to that of the Coalinga-Riverdale); (3) development of the shaly facies of the lower Cheneyan (zone A-2) and the Ciervian (zones B and C) stages confined to the deepest part of the geosyncline, approximately between the latitudes of Fresno and Coalinga.

Another feature revealed by Figure 14 is a rapid westward pinching out of several of the latest Cretaceous zones indicated in most of the diagrammatic cross sections and, particularly, in the section from Riverdale to Coalinga. Because of the small scale of the cross sections it could not be shown that this pinching-out is associated with the overlap of younger and younger Tertiary strata on the Cretaceous sediments. In the West Coalinga field for instance, the Cretaceous Ingramian (zone D-2) and Tracian (zone E) stages are overlain by the Kreyenhagen shales (Eocene Tejon stage of Clark and Vokes), and a well in the Waltham Creek area, Sec. 28, T. 21 S., R. 14 E., discovered the Cretaceous upper Weldonian stage (zone F-1) directly below the Pliocene Jacalitos formation. Similar conditions are present in the area west of Lost Hills where the beds belonging to the upper or lower parts of the Eocene Capay stage rest unconformably on the lower Ingramian (zone D-2) or on the Tracian (zone E) Cretaceous sediments.

Looking at the eastern ends of the Colusa-Marysville and Vacaville-Sacramento cross sections we may recall previous remarks that zone F′-1 (upper Weldonian) extends farther east than zone E (Tracian), and zone E extends farther east than the D-2 zone (lower Ingramian). These facts suggest that the farthest eastward transgression of the Upper Cretaceous sea was during the deposition of the upper Weldonian strata, whereas afterward a recession of the sea might have begun, so that the subsequent Upper Cretaceous zones either had not been deposited or had been eroded away.

Because of the method used for the compilation of the cross sections (Fig. 14), they give only a general idea of the structural features. This is particularly true about the Colusa-Marysville section which shows an exceedingly exaggerated structure of the Marysville-Buttes gas field. Actually the Cretaceous beds in this field display only local disturbance in a narrow belt bordering the Buttes volcanic neck, as illustrated by Stalder.[84]

TOPOGRAPHY OF CRETACEOUS SURFACE

A little more detailed, although still tentative, idea of the Cretaceous structure within the Great Valley may be gained from Figure 15, showing contours of the uppermost Cretaceous surface.

[84] Walter Stalder, "Structural and Commercial Oil and Gas Possibilities of Central Valley Region, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 4 (1932), Fig. 1 on p. 362.
———, "1941 Supplement to Sutter (Marysville) Buttes Development, Sutter County, California," *ibid.*, Vol. 26, No. 5 (1942), p. 853.

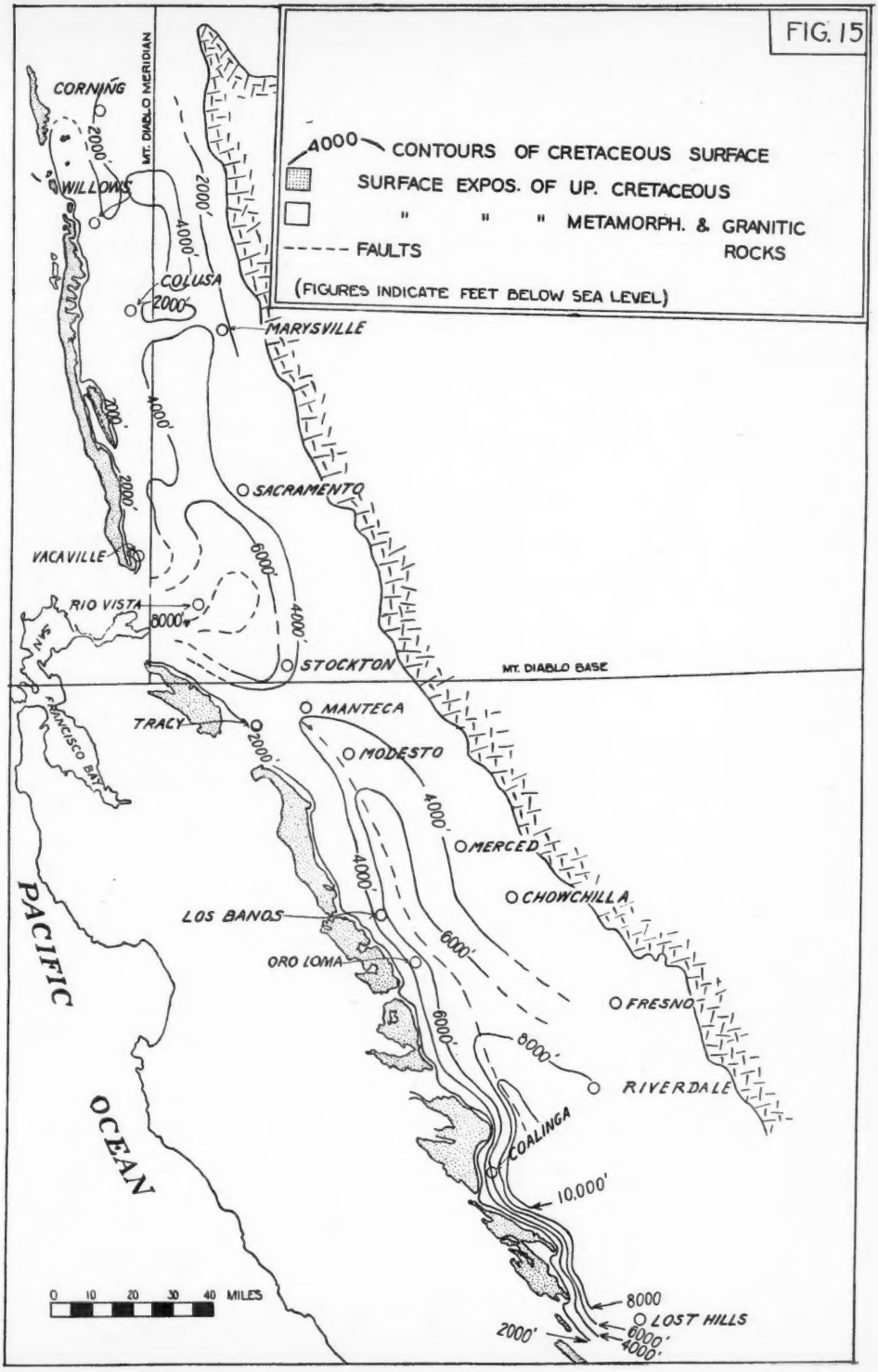


FIG. 15
4000 CONTOURS OF CRETACEOUS SURFACE
SURFACE EXPOS. OF UP. CRETACEOUS
" " " METAMORPH. & GRANITIC ROCKS
FAULTS
(FIGURES INDICATE FEET BELOW SEA LEVEL)
MT. DIABLO MERIDIAN
MT. DIABLO BASE
CORNING
WILLOWS
COLUSA
MARYSVILLE
SACRAMENTO
VACAVILLE
RIO VISTA
STOCKTON
MANTECA
TRACY
MODESTO
MERCED
CHOWCHILLA
LOS BANOS
ORO LOMA
FRESNO
RIVERDALE
COALINGA
LOST HILLS
SAN FRANCISCO BAY
PACIFIC OCEAN
2000'
4000'
6000'
8000'
10,000'
0 10 20 30 40 MILES

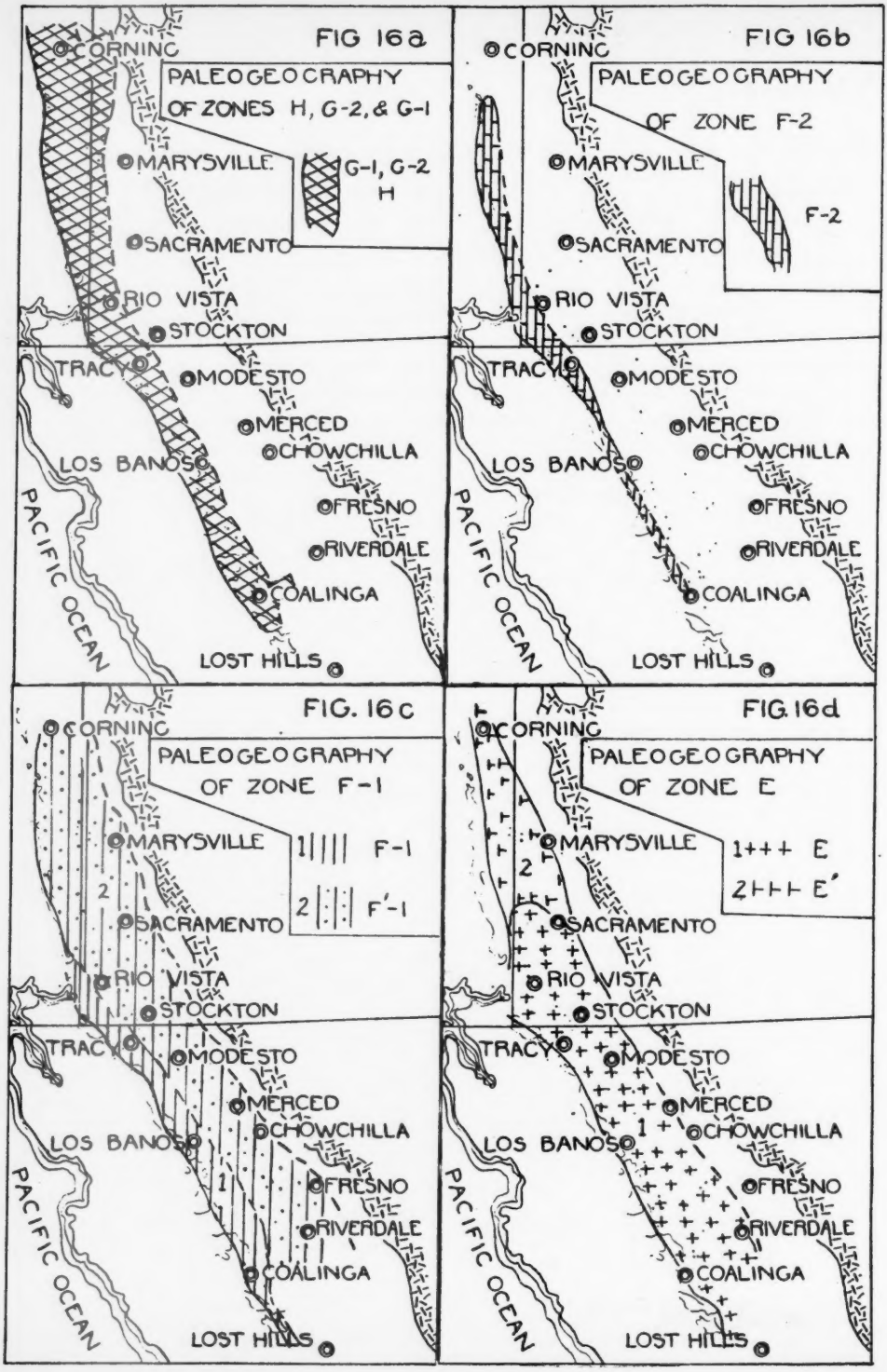


FIG 16a
PALEOGEOGRAPHY
OF ZONES H, G-2, & G-1
G-1, G-2
H
CORNING
MARYSVILLE
SACRAMENTO
RIO VISTA
STOCKTON
TRACY
MODESTO
MERCED
CHOWCHILLA
LOS BANOS
FRESNO
RIVERDALE
COALINGA
LOST HILLS
PACIFIC OCEAN
FIG 16b
PALEOGEOGRAPHY
OF ZONE F-2
F-2
FIG. 16c
PALEOGEOGRAPHY
OF ZONE F-1
F-1
F'-1
FIG. 16d
PALEOGEOGRAPHY
OF ZONE E
E
E'

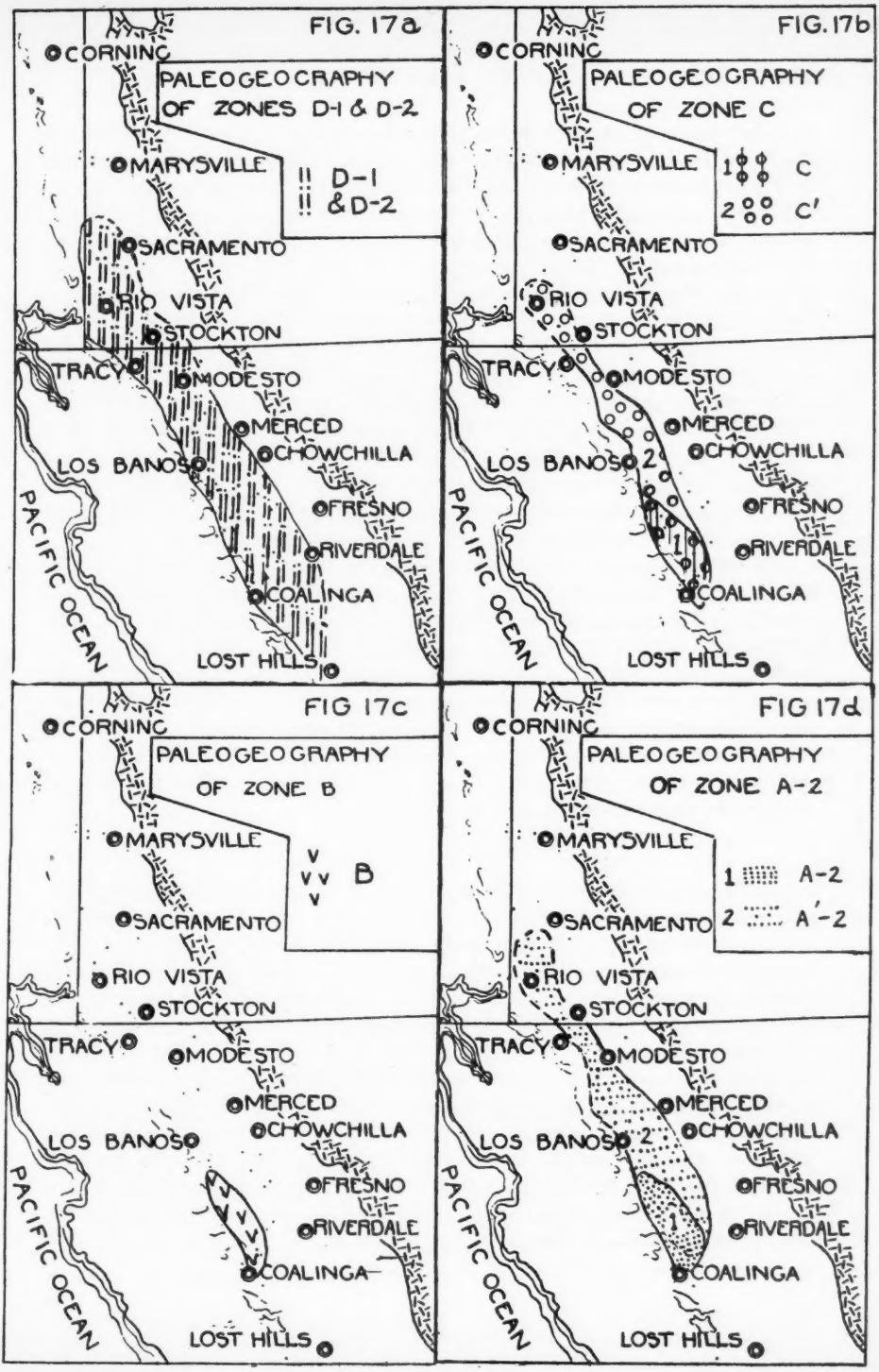


FIG. 17a
CORNING
PALEOGEOGRAPHY
OF ZONES D-1 & D-2
MARYSVILLE
D-1
& D-2
SACRAMENTO
RIO VISTA
STOCKTON
TRACY
MODESTO
MERCED
CHOWCHILLA
LOS BANOS
FRESNO
RIVERDALE
COALINGA
PACIFIC OCEAN
LOST HILLS
FIG. 17b
CORNING
PALEOGEOGRAPHY
OF ZONE C
MARYSVILLE
1 C
2 C'
SACRAMENTO
RIO VISTA
STOCKTON
TRACY
MODESTO
MERCED
CHOWCHILLA
LOS BANOS
FRESNO
RIVERDALE
COALINGA
PACIFIC OCEAN
LOST HILLS
FIG 17c
CORNING
PALEOGEOGRAPHY
OF ZONE B
MARYSVILLE
B
SACRAMENTO
RIO VISTA
STOCKTON
TRACY
MODESTO
MERCED
CHOWCHILLA
LOS BANOS
FRESNO
RIVERDALE
COALINGA
PACIFIC OCEAN
LOST HILLS
FIG 17d
CORNING
PALEOGEOGRAPHY
OF ZONE A-2
MARYSVILLE
1 A-2
2 A'-2
SACRAMENTO
RIO VISTA
STOCKTON
TRACY
MODESTO
MERCED
CHOWCHILLA
LOS BANOS
FRESNO
RIVERDALE
COALINGA
PACIFIC OCEAN
LOST HILLS

Studying these contours, one can more definitely recognize the two basins in the Great Valley, each plunging southeast: the Rio Vista depression at the lower end of the Sacramento basin, and the space between the 4,000-foot contours in the northern and southern parts of the Great Valley. This space is the previously mentioned isthmus extending easterly south of the Mount Diablo base between Tracy and Manteca. (The 4,000-foot contour must be closed in the northern part of the San Joaquin Valley (east of Tracy and south of Manteca.) This is evidenced by 3,200–3,900-foot depth at which the Cretaceous beds were encountered by wells at, and southeast of, Tracy (Sec. 15, T. 2 S., R. 5 E., and Sec. 14, T. 3 S., R. 6 E.) and south of Stockton (Sec. 8, T. 1 S., R. 6 E.), and by the more than 6,800-foot depth at which the Cretaceous strata were cored in a well north of the Mount Diablo base (T. 1 N., R. 6 E.). Because the isthmus represents a salient structural feature, it is proposed to name it the Manteca isthmus.

Figure 15 shows also that the area to which the shaly facies of the lower Chenyan and Ciervian stages (zones A-2, B, and C) are confined, coincides with the deepest southwesterly portion of the San Joaquin geosyncline.

In the Sacramento Valley is seen more clearly the minor structural complication caused by the Buttes volcanics in the central part of the broad syncline of the valley. In addition, a minor high in the Cretaceous surface is revealed by wells northeast of Willows (T. 20 N., R. 2 W.), and another minor complication appears southeast of the Rumsey Hills and west of Sacramento, where a bend in the 4,000-foot contour has been drawn to comply with structural observations reported by some geologists. Closure of the 2,000-foot contour, tentatively indicated in Figure 15, is suggested by the shallow depth at which the Cretaceous beds were encountered by wells in T. 28 N., R. 2 W., and T. 28 N., R. 4 W., and also by the exposures in the area of Redding.

PALEOGEOGRAPHY OF ZONES

In the compilation of the paleogeographic maps shown in Figures 16 and 17, the western borders of the zones are drawn to coincide with the western borders of the exposures of the corresponding zones. The demarcation of the eastern boundaries is made from data obtained by the writer from his own studies, and from the locations of the wells reported by other workers as having stopped in the Cretaceous.[85] It is assumed that the most easterly of these wells (those in Sec. 25, T. 6 N., R. 7 E.; Sec. 7, T. 4 N., R. 8 E.; Sec. 22, T. 10 S., R. 17 E.; and Sec. 29, T. 16 S., R. 23 E.) mark the eastern boundary of zone F′-1, because this zone appears to extend (in the southern part of the Sacramento Valley and in the San Joaquin Valley) farther east than any of the other zones. To differentiate the more accurately defined eastern boundaries from those drawn on the basis of insufficient data, the former are shown with solid lines, the latter with broken lines. The presence of zones G-1, G-2, F′-1, E, D-2, D-1, and A′-2 beneath the Rio Vista depression is suggested by the finding of these zones in the wells

[85] *California Div. Mines Bull. 118*, Pt. 3 (1943), pp. 637–64.

bordering the depression and in the outcrops on the north side of Mount Diablo.

Because of the meagerness of the data regarding the subsurface extent of H, G-2, and G-1 zones (the Delevanian, lower Cachenian, and Upper Cachenian stages), the paleogeography of all these zones is shown on one map (upper left, Fig. 16). Comparative size of the areas covered by each of these zones separately can not be outlined except in a general way: the G-1 zone extends farther eastward than the G-2 zone, and G-2 zone extends farther eastward than the H zone. The very slight variation in the microfaunal content of the beds of the G-1 and G-2 zones in different parts of the Great Valley, and the very uniform features of the strata of the H zone, wherever they have been found, suggest that during the Delevanian and Cachenian stages conditions of deposition were nearly the same (probably under fairly deep waters) over all the area covered by the Cretaceous sea, except in the vicinity of shore lines.

The record concerning the lower Weldonian stage (F-2 zone) is more complete and indicates that during this stage the area under the sea was definitely more narrow (as compared with that covered by the sea during the deposition of the G-1 zone), and extended eastward only for a short distance from the western coast of the sea. It may be added that the beds of the F-2 zone represent, presumably, a coarse-grained facies developed along a fairly steep western coast and pinching out rather rapidly toward the east. However, as in the case of older zones, the microfaunal content of the lower Weldonian beds gives no evidence of any perceptible ecological variations in the conditions in the Great Valley during that part of the Upper Cretaceous history. The waters throughout lower Weldonian time appear to have remained fairly deep and cool.

The paleogeography of the upper Weldonian stage (F-1 and F′-1 zones) may be characterized by two features: (1) the farthest eastern extension of the transgressing Upper Cretaceous sea into the Great Valley (except in its most northerly portion); and (2) in the beds of this stage there is the earliest evidence of two ecologically different facies. The deeper facies forms a narrow belt along the west side of the valley between Vacaville and Coalinga, and a more shallow facies is developed in the larger remaining part of the basin.

The distribution of the Tracian strata (E and E′ zones) gives a clear indication of a recession of the Upper Cretaceous sea in southeasterly and westerly directions. North of Sacramento there is only a shallow facies of the Tracian stage (E′ zone), and it is confined approximately to the western half of the Sacramento Valley.

The Tracian beds of the deeper-water facies (E zone), although covering a large part of the Great Valley basin, south of Sacramento, do not extend as far eastward as those of the preceding stage.

During the time of the Ingramian stage (D-2 and D-1 zones), because of the continuing recession of the sea in the same two directions, the northwestern part of the Great Valley had emerged above sea-level, and the eastern shore line had moved still farther west.

The deposition of the latest Upper Cretaceous beds (C and B zones) was limited to the more restricted areas of the San Joaquin basin; and the shaly facies of the lower and upper Ciervian stage are found in only the small deepest part of the geosyncline near its western slope.

In the same deepest part of the geosyncline were deposited (without interruption) the lower beds of the shaly facies of the lower Cheneyan stage (A-2 zone). By the end of that time, however, a minor submergence took place, due to which the sea transgressed again a little toward the east and for a considerable distance northward, and deposited the silty facies of the A′-2 zone. This episode was a prelude to the final separation of the San Joaquin and Sacramento basins caused by subsidence of the Rio Vista area and by the formation of the Manteca peninsula along the southern border of this area.

The history discussed in this paper ended with the deposition (in the already isolated Sacramento and San Joaquin basins) of the sandy beds of the A-1 zone assigned by the writer to the upper Cheneyan stage. This determination of the age of A-1 beds is only tentative, yet even if it were wrong, the general picture would not change much, because what is called the A-1 zone can not be younger than some later part of the Paleocene (Martinez or Meganos).

To conclude this paleogeographic sketch, the writer desires to make a few remarks about the source of the Upper Cretaceous sediments. As pointed out by Reed[86] and Anderson,[87] the conglomerates observed in the Upper Cretaceous exposures on the west side of the San Joaquin Valley indicate a western source. In search for this source, Reed advanced the theory that the Upper Cretaceous strata might have been made up of detritus transported from the folded and uplifted Lower Cretaceous beds of the Coast Ranges. To the present writer it seems significant that the deposits of the lower and upper Weldonian stages (zones F-2 and F-1), which were laid down during the progressive eastward transgression of the Cretaceous sea, show a rapid change from sands to shales in easterly directions. A western source of the Weldonian sediments, in agreement with Reed's idea, is thus indicated. But, on the other hand, the beds of the subsequent Tracian and Ingramian stages (zones E and D) are sandier on the east than they are in outcrops on the west side of the basin (between Oat Gulch and north side of Mt. Diablo). These beds were deposited after the beginning of regression of the Cretaceous sea, and they suggest an easterly source. In view of these facts, and also because of the "Santa Lucia orogeny" recognized by Taliaferro,[88] and F. M. Anderson's remark on the probability "of repeated uplifts" during Upper

[86] Ralph D. Reed, "California's Record in the Geological History of the World," *California Div. Mines Bull. 118*, Pt. 2 (1941) p. 111.

[87] F. M. Anderson, "Cretaceous Sedimentary Succession in California and Oregon," *Proc. Sixth Pacific Sci. Cong.*, Vol. 1 (1939), p. 394.

[88] N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges of California," *California Div. Mines Bull. 118*, Pt. 2 (1941), pp. 130–31.
———, "Cretaceous and Paleocene of Santa Lucia Range, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 4 (1944), pp. 484–85.

Cretaceous time,[89] it seems reasonable to assume that the source of the Upper Cretaceous sediments did not remain the same during that part of the Mesozoic history. Some of these sediments might have come from the west, others from the east, and still others, possibly, from the northwest.

SUMMARY

The beds in the Great Valley forming the part of the column between the base of the Martinez formation and the top of the Shasta series can be divided into twelve foraminiferal zones which seem to represent well defined time-stratigraphic units. The zones can be grouped into seven stages. These stages and the zones which they contain are as follows.

Upper and lower Cheneyan stages (*zones A-1 and A-2*).—Comprise the beds penetrated by the Jergins Oil Company's Cheney Ranch well No. 1 below the base of the Martinez and the top of the typical Moreno shale. The organic content of these beds and their stratigraphical relations to the overlying and underlying formations indicate pre-Martinez Paleocene age of the Cheneyan stage. In the most southwesterly part of the San Joaquin Valley the lower Cheneyan stage (zone A-2) is represented by shales and silty shales. In the subsurface sections in the middle part of the San Joaquin Valley and in the outcrops along its western side northwest of the Pacheco Pass the lower Cheneyan stage is made up of an ecologically different and probably shallower facies (zone A′-2).

With less certainty, and chiefly on the basis of stratigraphical position, the sands of the upper Cheneyan stage are assumed to extend into the Sacramento Valley.

One of the characteristics of the Cheneyan strata is the sporadic occurrence of some of the Foraminifera redeposited from older Cretaceous beds.

In the series embracing the Upper Cretaceous column between the top of the Moreno and down to the base of the Panoche formation, as defined by R. Anderson and Pack, one can recognize ten zones which may be grouped into six stages. These stages are listed in descending order.

1. *Upper and lower Ciervian* (*zones B and C*) corresponding with the Moreno shale at its type locality. The lower Ciervian stage is represented by two facies, one composed of shales (zone C) and another of silty shales and silts (zone C′).

2. *Upper and lower Ingramian* (*zones D-1 and D-2*).—Correlative with the upper part of the type Panoche formation and also with the part of the Ingram Creek surface section from a horizon about 400 feet below the top of the Cretaceous section and down to the horizon about 3,407 feet below the top.

3. *Tracian stage* (*zone E*).—The lower part of the body of shales exposed in the Ingram Creek and mapped by R. Anderson and Pack as Moreno. This stage is best represented in the column penetrated by the Amerada Petroleum Corporation's F. D. L. well No. 1 (near Tracy) between depths of 5,715 feet and 6,900 feet. A shallower-water facies of the stage (zone E′) is supposed to cover the part

[89] F. M. Anderson, *op. cit.*

of the Sacramento Valley North of the line connecting Vacaville with Sacramento.

4. *Upper and lower Weldonian stage (zones F-1, F'-1, and F-2).*—The surface equivalents are the Joaquin Ridge sandstone, as defined by J. Q. Anderson in the Alcalde Hills section, and the Forbes, Guinda, and upper part of the Funks formations in the Putah Creek section, as classified by Kirby. In the area along the west side of the San Joaquin Valley the upper Weldonian strata belong to a deep- and cool-water facies (zone F-1); in the central part of the same valley and throughout the Sacramento basin a distinctly shallower- and warmer-water facies of the upper Weldonian stage (zone F'-1) is developed.

5. *Upper and lower Cachenian stage (zones G-1 and G-2).*—Best developed along the west side of the Sacramento Valley. Correlatives of the upper Cachenian stage (zone G-1) are: the lower part of Kirby's Funks formation in the Putah Creek section; the lower 475 feet of Kirby's type Forbes formation exposed on the crest of the Rumsey Hills; and members VI, V, and upper part of member IV of the Chico sediments, as classified by Popenoe in the Redding district. In the San Joaquin Valley the upper Cachenian stage is best represented by that part of the Moreno Gulch section between 7,650 feet and 10,165 feet below the top of the type Moreno. The Foraminifera typical of the lower Cachenian stage (zone G-2) have been found in: the Sites formation and in the upper part of the Yolo formation, as described by Kirby in the Putah Creek and Cache Creek sections; in the lower part of member IV and in member II of Popenoe's divisions of the Chico near Redding, and in the part of the Moreno Gulch section between 10,170 feet and 12,000 feet below the top of the type Moreno.

6. *Delevanian stage.*—Embraces the lower part of the Yolo and the whole thickness of the Venado formations of Kirby, and also the lowest 14,000 feet of the Moreno surface section.

The areal distribution of the foraminiferal zones and of their ecological variants makes it possible to restore the paleogeography of the Upper Cretaceous sea as follows.

During the deposition of the Delevanian and Cachenian strata the western part of the Great Valley was covered by waters of about even depth, and the sea was slowly transgressing eastward (particularly in the most northerly portion of the valley).

This eastward transgression reached its maximum in the upper Weldonian stage all over the Great Valley, except in its most northerly part. The deeper-water facies of the upper Weldonian stage was confined to a narrow belt along the west side of the valley between Vacaville and Coalinga.

From the beginning of Tracian time and through the subsequent stages, the bottom of the sea was continuously plunging in a southeasterly direction simultaneously with some tilting toward the southwestern end of the San Joaquin Valley. Due to the plunging the northern part of the Sacramento Valley (north of Sacramento), which in Tracian time had been subject to only shallow-water

sedimentation, emerged above the sea in Ingramian time, and the deposition in the later stages was largely restricted to the western half of the San Joaquin Valley. Shaly facies of the Ciervian stage was laid down in only a small southwestern portion of the San Joaquin Valley between Oro Loma and Coalinga.

At the end of the lower Cheneyan stage the sea transgressed again northward, probably, some distance beyond the town of Rio Vista, and also transgressed to the east as far as the western border of the Helm oil field.

The end of the lower Cheneyan time was also marked by sinking of the area around Rio Vista and by formation of the Manteca isthmus (a continental barrier just south of the Rio Vista area) due to which the Sacramento and San Joaquin basins became completely isolated from each other.

The two isolated basins, each plunging southeast, and also the Manteca isthmus and the Rio Vista depression can be clearly seen on the map showing the Cretaceous surface. The map also shows the axis of the Great Valley geosyncline extending almost parallel with, and near, the west side of the valley, and the shaly facies of the Ciervian and the lower Cheneyan stages coinciding with the deepest part of the San Joaquin geosyncline.

Lithological characteristics of the Upper Cretaceous beds and the established directions of the transgression and recession of the Upper Cretaceous sea suggests that during the earlier stages (particularly during the Weldonian) the sediments came from a western source. On the other hand, detritus of which the beds of the later stages are composed (Tracian, Ingramian, and Ciervian) might have come from the east and, partly, from the northwest.

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SIGNIFICANCE OF UPPER CRETACEOUS FOSSILS FROM WELLS IN MISSISSIPPI[1]

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ABSTRACT

This paper is based on macrofossils obtained from core samples from 17 deep wells in Mississippi, distributed as follows: 8 in the Heidelberg field, 5 in the Eucutta field, 1 in Jones County, 1 in Simpson County, 1 in Jefferson Davis County, and 1 in Hinds County. The stratigraphic position of the significant fossils in the Eucutta and Heidelberg fields is shown diagrammatically in Figures 1 and 2. The presence of beds of Austin age is indicated by the following species: *Inoceramus undulatoplicatus* Roemer, *Inoceramus* aff. *I. umbonatus* Meek and Hayden, and *Gryphaea aucella* Roemer. Closely underlying the zone containing these species is a zone 160 feet or less in thickness characterized by the shells of *Ostrea oleana* Stephenson, a recently described species known only from these wells. The presence of this oyster in wells as far apart as the Eucutta field and the J. R. Ball well No. 1 in Hinds County indicates that this zone is widespread in the subsurface in central Mississippi. Closely underlying the *Ostrea oleana* zone in several of the wells is a zone containing poorly preserved oysters that appear to belong to *Ostrea sannionis* White, a species known only from beds in northeast Texas corresponding in age with the base of the Austin chalk, and with beds of early Niobrara age in Utah. At a somewhat lower level were found poorly preserved ammonites questionably identified as *Prionotropis*, an upper Eagle Ford genus. Very imperfect shell impressions from the depth of 6,151 to 6,153 feet in the Helen Morrison well No. 1 in the Heidelberg field suggest species known in the Lewisville formation in Texas.

It has been the writer's privilege in recent months to study Upper Cretaceous macrofossils from core samples obtained from 17 deep wells in Mississippi. The samples from 16 of the wells were furnished by Roy T. Hazzard, district geologist for the Gulf Refining Company of Louisiana, and were distributed as follows: 8 wells in the Heidelberg field, Jasper County; 5 wells in the Eucutta field, Wayne County; one well in Jones County; one well in Simpson County; and one well in Jefferson Davis County. The seventeenth well is in Hinds County, and the samples from it were furnished by Grover E. Murray, Jr., geologist for the Magnolia Petroleum Company.

The writer has not had an opportunity to become well informed in regard to the geologic features revealed by the wells already drilled in the Heidelberg and Eucutta oil fields, and the conclusions here given are based entirely on the evidence afforded by the fossils from the cores. Because of the poor state of preservation of many of the fossils and their paucity in some of the cores it may be necessary later to revise these conclusions as additional more diagnostic material becomes available.

Nearly all the fossils obtained from the cores are imperfectly or incompletely preserved. Some of them can be identified specifically, but many can be assigned only to genera, or to the larger, more inclusive groups of organisms. Several previously described species having value as index fossils are recognized. One recently described species of oyster, *Ostrea oleana* Stephenson,[3] is recorded from

[1] Manuscript received, March 12, 1945. Published by permission of the director of the Geological Survey.

[2] Principal geologist, Geological Survey, United States Department of the Interior.

[3] Lloyd W. Stephenson, "A New Upper Cretaceous Oyster from Deep Wells in Mississippi," *Jour. Paleon.*, Vol. 19, No. 1 (January, 1945), pp. 72–74, text Figs. 1–7.

10, questionably 11, of the wells, and its occurrence at locations as far apart as Wayne and Hinds counties, with an observed maximum vertical range of only 160 feet, demonstrates its value as an index fossil in central Mississippi. The common occurrence of this oyster in the well cores shows that it is common in more or less glauconitic sand and sandstone forming a zone which is penetrated in the wells at differing depths ranging from 4,555 to 5,569 feet below the surface (=4,210 to 5,185 feet below sea-level).

Notes on the significance of the fossils obtained from each well are given in the following paragraphs, and the position of the more significant fossils from the wells in the Heidelberg and Eucutta fields is indicated diagrammatically in Figures 1 and 2. The names of the fossil forms having significance in correlation in our present state of knowledge are given in the diagrams; all others are omitted.

The evidence afforded by the fossils, as recorded in detail on subsequent pages, demonstrates clearly the presence in the subsurface of Mississippi of beds of middle and lower Austin age and of upper Eagle Ford age, and the probable presence of beds representing the Lewisville unit of Texas. The material studied affords no direct paleontologic tie with the formations appearing at the surface at the north and northeast in Mississippi and Alabama. It may be reasonably assumed, however, that the beds in the well sections demonstrated to be of middle and lower Austin age are the downdip equivalents of the Eutaw formation, for the correlation of the Tombigbee sand member of the Eutaw with the *Gryphaea wratheri* zone in the Austin chalk is well established by fossil evidence. In Texas the latter zone lies near or a little above the middle of the Austin chalk and has been traced from Dallas County to Guadalupe County, a distance of 250 miles. In Alabama the zone lies in the upper part of the Tombigbee sand and has been traced from near Eutaw, Greene County, to Montgomery, a distance of 100 miles. The accuracy of this correlation is further confirmed by the species *Inoceramus undulatoplicatus* Roemer, which was identified in the Rowell well No. 1 at the depth of 5,251 feet (Fig. 2) and which in Texas occupies a narrow zone closely underlying the *Gryphaea wratheri* zone.

Eucutta field. Gulf Refining Company's Charles Green well No. 1, SE. ¼, NE. ¼ of Sec. 2, T. 9 N., R. 9 W., Wayne County. Elevation, 276 feet D. F. (Fig. 1).

The specimen identified as *Inoceramus umbonatus* Meek and Hayden?, found at 5,055 feet, is small and badly crushed, but it obviously belongs to the group of *Inoceramus* to which *I. umbonatus* Meek and Hayden, *I. exogyroides* Meek and Hayden, and *I. involutus* Sowerby belong. This indicates the Austin (Niobrara) age of the containing stratum. In confirmation of this correlation is the presence of *Gryphaea aucella* Roemer, an Austin species, at the depth of 5,085 feet (Fig. 1). The specimens identified as *Inoceramus* sp. belong to a form of the genus that is believed to be restricted in its vertical range to beds younger than the Eagle Ford shale.

Eucutta field. Gulf Refining Company's G. S. Stanley well No. 8, NW. ¼, NE. ¼ of Sec. 1, T. 9 N., R. 9 W., Wayne County. Elevation, 321 feet D. F. (Fig. 1).

The new oyster, *Ostrea oleana*, is present in abundance in core No. 7 at the depth of 5,145 feet; this is the locality of the holotype and 15 paratypes of this species. The species is questionably identified from core No. 8 at the depth of 5,155 feet and also in core No. 9, at 5,166–5,186 feet. Core No. 10, at 5,186–5,200 feet, yielded one right valve of a young shell of *Ostrea sannionis* White, indicating earliest Austin age.

Eucutta field. Gulf Refining Company's G. S. Stanley well No. 7, SW. ¼, SE. ¼ of Sec. 36, T. 10 N., R. 9 W., Wayne County. Elevation, 268 feet D. F. (Fig. 1).

Ostrea oleana, if correctly identified from core No. 2, depth 5,123–5,143 feet, establishes the position of the *Ostrea oleana* zone in this well. The character of the matrix, a gray micaceous, somewhat glauconitic sand, is corroborative of this correlation.

Eucutta field. Gulf Refining Company's A. J. Boykin well No. 1, NW. ¼, SE. ¼ of Sec. 36, T. 10 N., R. 9 W., Wayne County. Elevation 265 feet. D. F. (Fig. 1).

The presence of a full-grown shell of *Gryphaea aucella* Roemer determines the Austin age of core No. 1 at the depth of 5,006 feet; since this species ranges through nearly the full thickness of the Austin chalk its presence here does not determine the position of the core with respect to the top or bottom of the unit.

Eucutta field. Gulf Refining Company's Stanley well No. 1, S.E ¼, SE. ¼ of Sec. 36, T. 10 N., R. 9 W., Wayne County. Elevation 335 feet D. F. (Fig. 1).

The Austin age of the core at the depth of 4,964–4,971 feet is indicated by the presence of *Gryphaea aucella* Roemer. A fragment of a large *Inoceramus* in the core has the aspect of a species of post-Eagle Ford age. *G. aucella* is also present in a core at 4,977–4,979 feet. The imprint of *Cymella?* sp. in gray shale at 5,112–5,123 feet is similar to that of *Cymella?* sp. in the Stanley well No. 8 at the depth of 5,186–5,200 feet. The latter, however, is a crushed specimen having somewhat coarser concentric sculpture in the umbonal region, and it may be a different species.

Heidelberg field.[4] Gulf Refining Company's J. Morgan well No. 2, SW. ¼, SW. ¼ of Sec. 34, T. 1 N., R. 12 E., Jasper County. Elevation, 400 feet D. F. (Fig. 2).

Gryphaea aucella Roemer, an Austin species, was identified in a core sample taken at the depth of 4,986 to 4,988 feet. The *Ostrea oleana* zone was penetrated between depths of 5,108 and 5,218 feet, as shown by the presence of this oyster in cores at the following depths: 5,108–5,109 feet; 5,158½ feet; 5,171–5,185 feet; 5,205–5,218 feet. The shells were abundant in some of the cores. This zone is interpreted to be lower Austin in age. Associated with *O. oleana* is a poorly

[4] A general account of the geologic conditions in the Heidelberg field is given by R. A. McCullough in a short paper entitled, "Geology of the Heidelberg Oil Field," published in *Oil* (New Orleans, November, 1944), pp. 8–9.

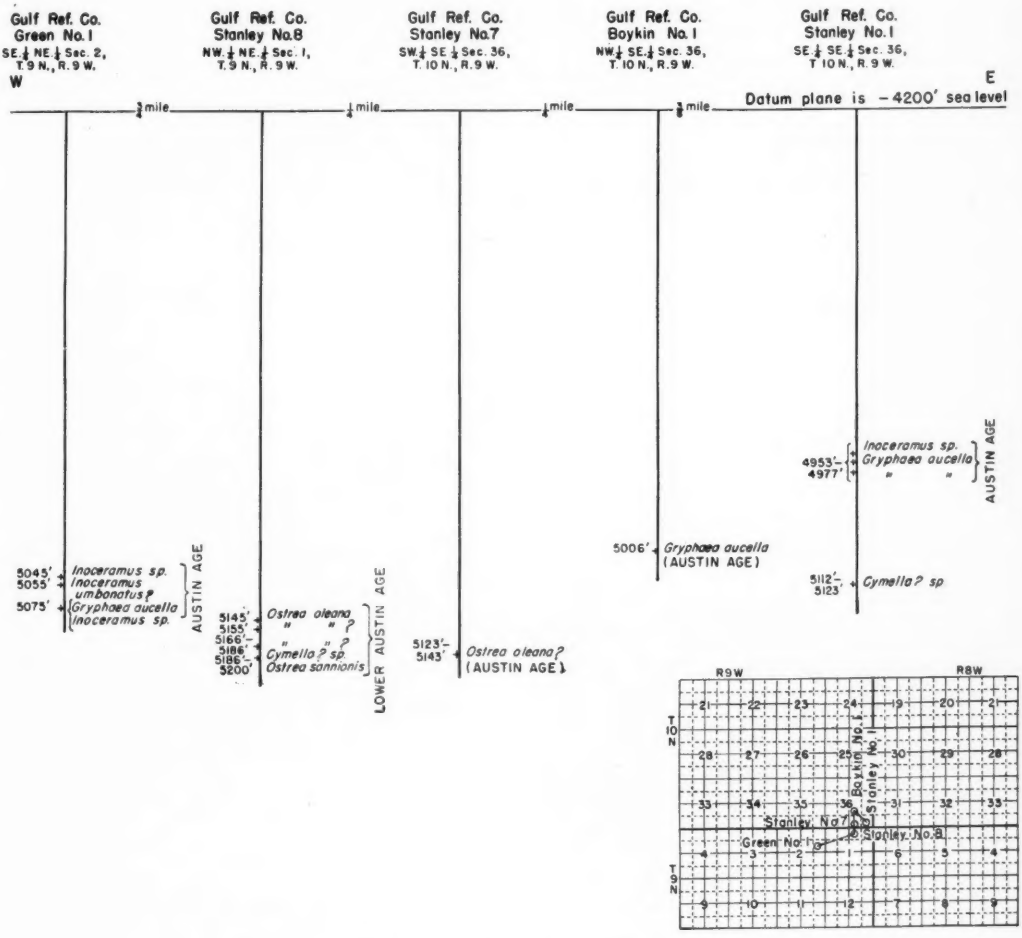


FIG. 1.—Position of Upper Cretaceous index fossils in wells in Eucutta field, Wayne County. Approximate distances between wells in fractions of a mile.

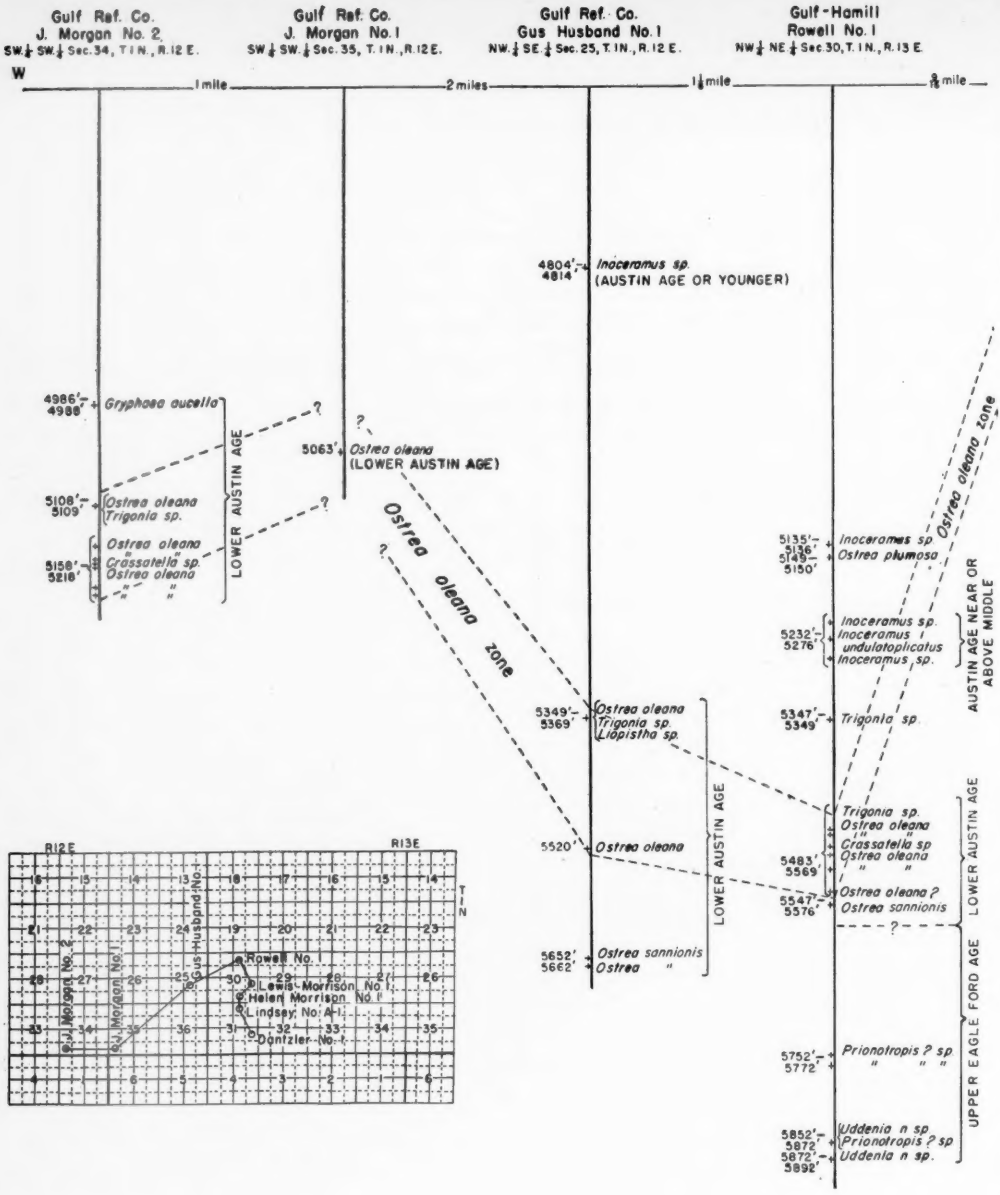
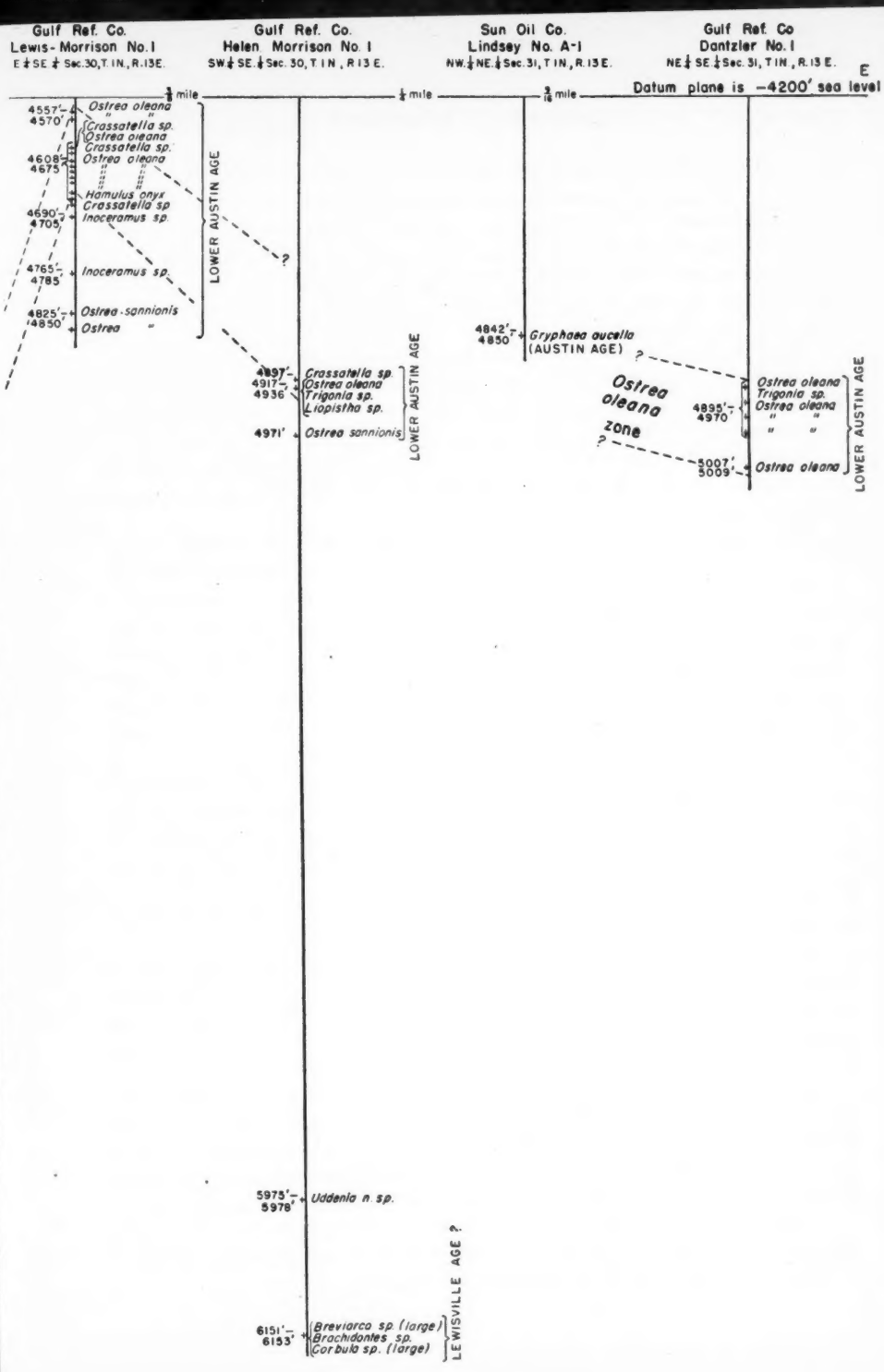

Gulf Ref. Co.
J. Morgan No. 2
SW¼ SW¼ Sec. 34, T. 1 N., R. 12 E.
Gulf Ref. Co.
J. Morgan No. 1
SW¼ SW¼ Sec. 35, T. 1 N., R. 12 E.
Gulf Ref. Co.
Gus Husband No. 1
NW¼ SE¼ Sec. 25, T. 1 N., R. 12 E.
Gulf-Hamill
Rowell No. 1
NW¼ NE¼ Sec. 30, T. 1 N., R. 13 E.
W
1 mile
2 miles
1¼ mile
⅜ mile
4986'–4988' Gryphaea aucella
5063' Ostrea oleana (LOWER AUSTIN AGE)
5108'–5109' Ostrea oleana Trigonia sp.
5156'–5218' Ostrea oleana Crassatella sp. Ostrea oleana
LOWER AUSTIN AGE
Ostrea oleana zone
4804'–4814' Inoceramus sp. (AUSTIN AGE OR YOUNGER)
5349'–5369' Ostrea oleana Trigonia sp. Liopistha sp.
5520' Ostrea oleana
5652'–5662' Ostrea sannionis Ostrea "
LOWER AUSTIN AGE
5135'–5136' Inoceramus sp.
5148'–5150' Ostrea plumosa
5232'–5276' Inoceramus sp. Inoceramus undulatoplicatus Inoceramus sp.
AUSTIN AGE NEAR OR ABOVE MIDDLE
5347'–5349' Trigonia sp.
Trigonia sp. Ostrea oleana " " Crassatella sp. Ostrea oleana " "
5483'–5569'
5547'–5576' Ostrea oleana? Ostrea sannionis
LOWER AUSTIN AGE
5752'–5772' Prionotropis? sp. " " "
5852'–5872' Uddenia n sp. Prionotropis? sp.
5872'–5892' Uddenia n sp.
UPPER EAGLE FORD AGE
R12E
R13E
T 1 N
Rowell No. 1
Gus Husband No. 1
G.J. Morgan No. 2
G.J. Morgan No. 1
D.L. Lewis-Morrison No. 1
Helen Morrison No. 1
Lindsey No. A-1
Dantzler No. 1

FIG. 2.—Position of Upper Cretaceous index fossils in wells in Heidelberg field, Jasper



County. Approximate distances between wells in miles and fractions of miles.

preserved *Crassatella* that probably belongs to an undescribed species. An incomplete, poorly preserved specimen of *Trigonia* from core No. 7 at the depth of 5,108 to 5,109 feet is probably the same species recorded from the *Ostrea oleana* zone in several wells in the Heidelberg field, as noted on following pages.

Heidelberg field. Gulf Refining Company's J. Morgan well No. 1, SW. ¼, SW. ¼ of Sec. 35, T. 1 N., R. 12 E., Jasper County. Elevation, 418 feet D. F. (Fig. 2).

Shells of *Ostrea oleana* are present in considerable numbers in core No. 10 at 5,063 feet. This bed probably corresponds with a sample from core No. 11, J. Morgan well No. 2, taken at the depth of 5,179–5,181 feet; the matrix in each well is greenish gray, strongly glauconitic sandstone.

Heidelberg field. Gulf Refining Company's Gus Husband well No. 1, NW. ¼, SE. ¼ of Sec. 25, T. 1 N., R. 12 E., Jasper County. Elevation, 390 feet D. F. (Fig. 2).

The imprints of *Inoceramus* in a sample, depth 4,804–4,814, though very incomplete, pertain to a species that is believed to be of Austin age or younger.

In this well *Ostrea oleana* was first met with in core No. 8 at the depth of 5,349–5,369 feet. The shells are numerous, though mostly half-grown or younger. In the same core are several imprints of *Trigonia* probably belonging to the species mentioned as present in core No. 7 of the J. Morgan well No. 2, depth 5,108–5,109 feet. There are also present imprints of an undescribed species of *Liopistha* that appears to be identical with specimens in core No. 4, depth 4,917–4,936 feet in the Helen Morrison well No. 1 (Fig. 2).

Several young shells of *Ostrea oleana* were obtained from a sample at the depth of 5,520 feet, indicating a thickness of at least 160 feet for this zone in this well.

Core No. 12, depth 5,652–5,672 feet, yielded in its top layer an oyster that is referred with some confidence to *Ostrea sannionis* White, indicating earliest Austin age.

Heidelberg field. Gulf-Hamill's Rowell well No. 1, NW. ¼, NE. ¼ of Sec. 30, T. 1 N., R. 13 E., Jasper County. Elevation, 374 feet D. F. (Fig. 2).

Incomplete shells of several large individuals of *Inoceramus* were found in core No. 1 at 5,135–5,136 feet. Although not specifically identifiable they appear to pertain to a section of the genus that is not known in beds older than the Austin chalk. The containing matrix is impure chalk. From the following data it is clear that the age of these shells is upper Austin.

A small oyster, identified as *Ostrea plumosa* Morton?, was obtained from a core sample at 5,149–5,150 feet. This species is common in Upper Cretaceous marine formations ranging in age from upper Austin to the end of the Cretaceous but has not been recorded from beds as old as the Eagle Ford shale. The oyster is closely associated with the incomplete imprints of a large *Inoceramus*.

A jumble of fragments of a large thick-shelled species of *Inoceramus*, such as are common in some layers of the Austin chalk in Texas, are present in core No. 6, in impure sandy chalk at the depth of 5,232–5,233 feet.

A very satisfactory correlation is afforded by an incomplete, but readily identifiable shell of *Inoceramus undulatoplicatus* Roemer, in core No. 7 at 5,251–5,252 feet. The shell covers a complete cross section of the core and exhibits the characteristic coarse concentric and radial ridges, and the finer growth markings of the species. In Texas this species, so far as the records of its distribution are known to me, is restricted in its vertical range to a zone 50 feet or less in thickness, lying near or a little above the middle of the Austin chalk. The zone has been recognized here and there along a linear distance of more than 450 miles. A convenient place to see this zone in outcrop is at the spillway below the dam of White Rock Reservoir, about 6 miles northeast of the post office at Dallas.

Prints of an *Inoceramus* of squarish outline, possibly *I. subquadratus* Schlüter, an Austin chalk species, present in core No. 8, depth 5,274–5,276 feet, is additional evidence of the Austin age of this part of the section.

Core No. 10, depth of 5,347–5,349 feet, yielded a fragment of *Trigonia* that is similar to, if not identical with, the one recorded from core No. 8, depth 5,349–5,369 feet, in the Gus Husband well No. 1.

A portion of a *Trigonia*, probably the same species as the one just mentioned, was found in core No. 17, depth 5,487–5,489 feet. Associated with it are several young shells of *Ostrea oleana*, and this oyster was obtained at several levels between this depth and the depth of 5,569 feet. An undescribed *Crassatella*, probably the same species as that recorded in the *Ostrea oleana* zone in the J. Morgan well No. 2, at the depth of 5,175–5,179 feet, was found in core No. 18 at the depth of 5,509–5,510 feet. The *O. oleana* zone is at least 86 feet thick in this well.

Ostrea sannionis White, indicating earliest Austin age, was found in core No. 22 at the depth of 5,575–5,576 feet. The matrix is dark gray sandy shale.

Fragments of small ammonites, questionably referred to *Prionotropis*, are present in the form of prints in dark gray shale, depth 5,752–5,772 feet, and similar prints were obtained from dark shale, depth 5,852–5,872 feet. In the same core and in the next core below, depth 5,872–5,892 feet, are numerous shells of *Uddenia*, a small bivalve belonging to an undescribed species. These shells are believed to indicate the Eagle Ford age of the shale.

Heidelberg field. Gulf Refining Company's Lewis-Morrison Unit well No. 1, NE. ¼, SE. ¼ of Sec. 30, T. 1 N., R. 13 E., Jasper County. Elevation, 343 D. F. (Fig. 2).

In this well the *Ostrea oleana* zone is at least 120 feet thick, as indicated by the presence of this oyster at the following depths: 4,557–4,570 feet; 4,608–4,675 feet. In this zone at the depth of 4,560–4,563½ feet are poorly preserved imprints of *Trigonia*, probably specifically the same as the one recorded from the Gus Husband well, depth 5,349–5,369 feet. Imprints of *Crassatella*, apparently belonging to the undescribed species recorded from the *O. oleana* zone in the J. Morgan well No. 2, are present at several levels in the same zone in this well. A worm tube in the basal part of this zone is identified as *Hamulus onyx* Morton, a species not known to range into beds older than the Austin chalk.

A medium-sized but incomplete shell of *Inoceramus* in Core No. 11, depth 4,690–4,705 feet, appears to belong to a roundish form of the genus that is known in the base of the Austin chalk and beds of that age.

Core No. 18, depth 4,825–4,830 feet, yielded numerous shells of *Ostrea sannionis* White, and several shells of the same species were obtained from core No. 19, depth 4,830–4,850 feet. They indicate earliest Austin age.

Heidelberg field. Gulf Refining Company's Helen Morrison well No. 1, SW. ¼, SE. ¼ of Sec. 30, T. 1 N., R. 13 E., Jasper County. Elevation, 322 feet D. F. (Fig. 2).

The *Ostrea oleana* zone was recognized in this well between depths 4,880 and 4,936 feet. In addition to *Ostrea oleana* the zone is marked by the presence of the undescribed species of *Trigonia* and *Crassatella* recorded from the zone in several of the preceding wells and by the undescribed species of *Liopistha* from the zone in the Gus Husband well No. 1.

A small ribbed oyster that appears to have lived in a crowded environment was obtained from core No. 8 at a depth of 4,971 feet; it matches fairly closely some of the individual variants among the large collections of *Ostrea sannionis* White available for comparison, and is referred questionably to that species.

Core No. 16, depth 5,975–5,987 feet, which is nearly a thousand feet deeper than the preceding core, is a dark gray shale containing an abundance of small shells, mainly bivalves, most of which are undescribed species having at present no value in correlation. One of them, however, *Uddenia* sp., represented by many shells, appears to belong to the undescribed species of *Uddenia* recorded from the Eagle Ford shale in Rowell well No. 1 at the depth of 5,852–5,872 feet. Presumably, it may be regarded as indicative of Eagle Ford age.

Samples of gray argillaceous sandstone from core No. 24 at the depth of 6,151–6,153 feet yielded several forms that resemble species in the Lewisville fauna of Texas, including *Breviarca* sp. (large), *Brachidontes* sp., and "*Corbula*" sp. (large).

Heidelberg field. Sun Oil Company's Mack Lindsey well No. A-1, NW. ¼, NE. ¼ of Sec. 31, T. 1 N., R. 13 E., Jasper County. Elevation, 329 feet D. F. (Fig. 2).

A characteristic species of the Austin chalk, *Gryphaea aucella* Roemer, is present in a core sample of gray sandstone, depth 4,842–4,850 feet.

Heidelberg field. Gulf Refining Company's Sallie E. Dantzler well No. 1, NE. ¼, SE. ¼ of Sec. 31, T. 1 N., R. 13 E., Jasper County. Elevation, 318 feet D. F. (Fig. 2).

Cores 5–10, depths 4,895–5,009, each contained shells of *Ostrea oleana*, indicating a thickness of at least 114 feet for the zone in this well.

Jones County. Gulf Refining Company's Masonite well No. C-1, Sec. 15, T. 9 N., R. 10 W.

Core samples from this well taken between depths of 5,428 and 5,556 feet were examined, and a few poorly preserved fossils were obtained from all of them.

The only one recognized as having definite value in correlation is *Ostrea oleana*, which was obtained at several levels between depths of 5,446 and 5,496 feet, showing a thickness of at least 50 feet of the *O. oleana* zone. Small specimens of *Crassatella*, which may be the young shells of the undescribed species recorded from this zone in several wells in the Heidelberg field, were found in the same association here.

Simpson County. Gulf Refining Company's A. J. Roberts well No. 1, Sec. 23, T. 2 N., R. 5 E. Elevation, 476 feet D. F.

Thirteen cores were submitted from this well from different depths between 7,075 and 8,908 feet. Ten of them down to 7,295 feet are more or less fossiliferous, and the remaining three to the bottom of the well are without fossils. Most of the fossils are in an imperfect state of preservation and are meaningless from the standpoint of correlation. However, a well preserved shell of *Gryphaea aucella* Roemer, an Austin species, was identified in core No. 6, depth 7,125–7,135 feet. Core No. 20, depth 7,265–7,275 feet, yielded a *Crassatella* that appears to be identical with the undescribed species of that genus obtained from the *Ostrea oleana* zone in several of the wells in the Heidelberg field. Although fragments of oyster shells were recognized in these cores the zone marker, *O. oleana*, was not identified among them.

Core No. 43, depth 7,488–7,498 feet, is a coarse conglomerate composed of quartz, siderite, and other pebbles in a matrix of coarse quartz sand.

No samples were submitted representing the 1,390 feet of section between depths of 7,498 and 8,888 feet. The two cores representing depths 8,888 to 8,908 consist mainly of dense gray sandstones and siltstones containing no fossils. These strata appear to be older than Upper Cretaceous.

Jefferson Davis County. S. W. Richardson's C. E. Berry well No. 1, Sec. 24, T. 9 N., R. 19 W. Elevation, 448 feet D. F.

Core No. 11, depth 7,833–7,843 feet, contains fragments of *Ostrea* and *Anomia* and the poorly preserved imprints of a species of *Crassatella* that is probably the same species as the *Crassatella* recorded from the zone of *Ostrea oleana* in several of the wells in the Heidelberg field. The matrix is a strongly glauconitic, calcareous, micaceous sandstone very much like that of the *O. oleana* zone.

No samples were submitted representing depths between 7,843 and 8,750 feet, a vertical distance of 907 feet. Four samples from cores Nos. 27–30 consist mainly of gray sandstone with scattered plant fragments, in part glauconitic and in part calcareous, with some interbedded dark gray sandy shale. A small "*Corbula*" in the upper half of core 29, depth 8,770–8,775 feet, and a large *Trigonarca*-like bivalve in core 30, depth 8,780 to 8,790 feet, though imperfectly preserved, suggest species in the fauna of the Lewisville unit.

Hinds County. J. V. Canterbury's J. R. Ball well No. 1, NW. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 7, T. 5 N., R. 1 W.

Two core samples were submitted from this well. One from the depth of 4,573 to 4,590 feet consisted of gray calcareous, micaceous sandstone, and yielded

specimens of *Ostrea oleana*, *Crassatella* sp., *Cardium* sp., *Cyprimeria* sp., "*Corbula*" sp., and several small unidentified bivalves. *O. oleana* is represented by one fairly well preserved adult shell with both valves present and by several small incomplete juvenile shells. The large shell is typical of the species. The *Crassatella*, though very imperfect, appears to be identical with the undescribed species of that genus recorded from the *O. oleana* zone in the Heidelberg field. The other fossils listed are too poorly preserved to be useful as horizon markers.

The other sample, depth 5,690–5,710 feet, is a coarse calcareous, pebbly sandstone, containing the shells of a somewhat irregular, medium-sized oyster having no particular characteristics with which to recognize its specific relationships. The specimens could be young non-typical shells of *Ostrea soleniscus* Meek, a Lewisville species. This possibility, together with their position 1,100 feet below the core containing *Ostrea oleana*, suggests the Lewisville age of this core.

Supplementary note.—Subsequent to the transmission of this paper for publication, a few fossiliferous core samples were received from Grover E. Murray, Jr., geologist for the Magnolia Petroleum Company, from two additional wells, one in the Heidelberg field and one in the Eucutta field. The first of these wells, the Windham-Herrington Unit No. 1, located 330 feet north and east of the southwest corner, SW. ¼, NW. ¼ of Sec. 35, T. 1 N., R. 12 E., Jasper County, about 1 mile north of the Gulf Refining Company's J. Morgan well No. 1, yielded several typical specimens of *Ostrea oleana* from gray glauconitic, calcareous sandstone, at depths of 5,140–5,154 feet and 5,170–5,190 feet. Dark gray sandy, finely micaceous shale, at the depth of 5,225–5,241 feet, yielded several poorly preserved mollusks, as did also a similar shale at the depth of 5,252–5,258 feet. Among the latter is an oyster believed to be a young shell of *Ostrea sannionis* White. On the basis of these fossils the beds penetrated between depths of 5,140 and 5,258 feet are interpreted to be lower Austin in age.

The second well, the Magnolia Petroleum Company's G. S. Stanley No. 2, located 660 feet south and west of the northeast corner of Sec. 18, T. 9 N., R. 8 W., Wayne County, about 2.5 miles south-southeast of the G. S. Stanley No. 8, at the depth of 5,085–5,095 feet, yielded parts of a large *Inoceramus* that appears to belong to a form of the genus present in the lower part of the Austin chalk of Texas and the lower part of the Niobrara chalk of the Western Interior.

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OCCURRENCE OF MIDDLE JURASSIC ROCKS IN WESTERN INTERIOR OF UNITED STATES[1]

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ABSTRACT

The occurrence of Middle Jurassic rocks in the Western Interior region of the United States is shown by the presence of the Bajocian ammonites, *Stemmatoceras* and *Defonticeras*, in the Twin Creek limestone of southeastern Idaho. The occurrence of Middle Jurassic rocks of the Bathonian stage is indicated by the presence of the ammonites, *Arctocephalites* and *Cranocephalites*, in the lower part of the Ellis formation of Montana. Marine Jurassic deposits older than the Bathonian appear to have been limited to the central part of the sedimentary trough and will probably be found only along the border area of Idaho and Wyoming, in north-central Utah, and in southwestern Montana.

Middle Jurassic rocks of the Bajocian and Bathonian stages definitely occur in the Western Interior region of the United States. Bajocian rocks have been identified only in the Freedom Quadrangle of southeastern Idaho and probably are not widely distributed. Bathonian rocks have been identified at many places in Montana and Wyoming and probably occur in Idaho, Utah, and the Dakotas. Most of the previous workers have assumed that the Sundance and Ellis formations and the Twin Creek limestone were entirely of Upper Jurassic age, and that the Middle Jurassic, if present, was represented by the nearly unfossiliferous Nugget and Navajo sandstones.[3] Suggestions of a Middle Jurassic age for part of the Ellis formation in the Yellowstone National Park area[4] and of the lower part of the Twin Creek limestone in southeastern Idaho[5] were not substantiated by fossils. Crickmay[6] concluded that the basal part of the Ellis formation of the Yellowstone National Park area was not older than the Callovian stage of the Upper Jurassic as shown by the presence of the ammonites *Peltoceras* and *Proplanulites*. Unfortunately, his specimens were not illustrated, or described, and are not available for examination.

The evidence presented herein for the presence of Middle Jurassic rocks is based on a field season in 1944 in north-central Montana, on a careful study of the type section of the Ellis formation near Bozeman, Montana, on brief examinations of the Jurassic sections on Cinnabar Mountain in the Yellowstone National Park area and in the Wind River basin of Wyoming, and finally on re-

[1] Manuscript received, March 12, 1945. Published by permission of the director of the Geological Survey.

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[3] A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., "Correlation of the Jurassic Formations of Parts of Utah, Arizona, New Mexico, and Colorado," *U. S. Geol. Survey Prof. Paper 183* (1936), pp. 55–58.

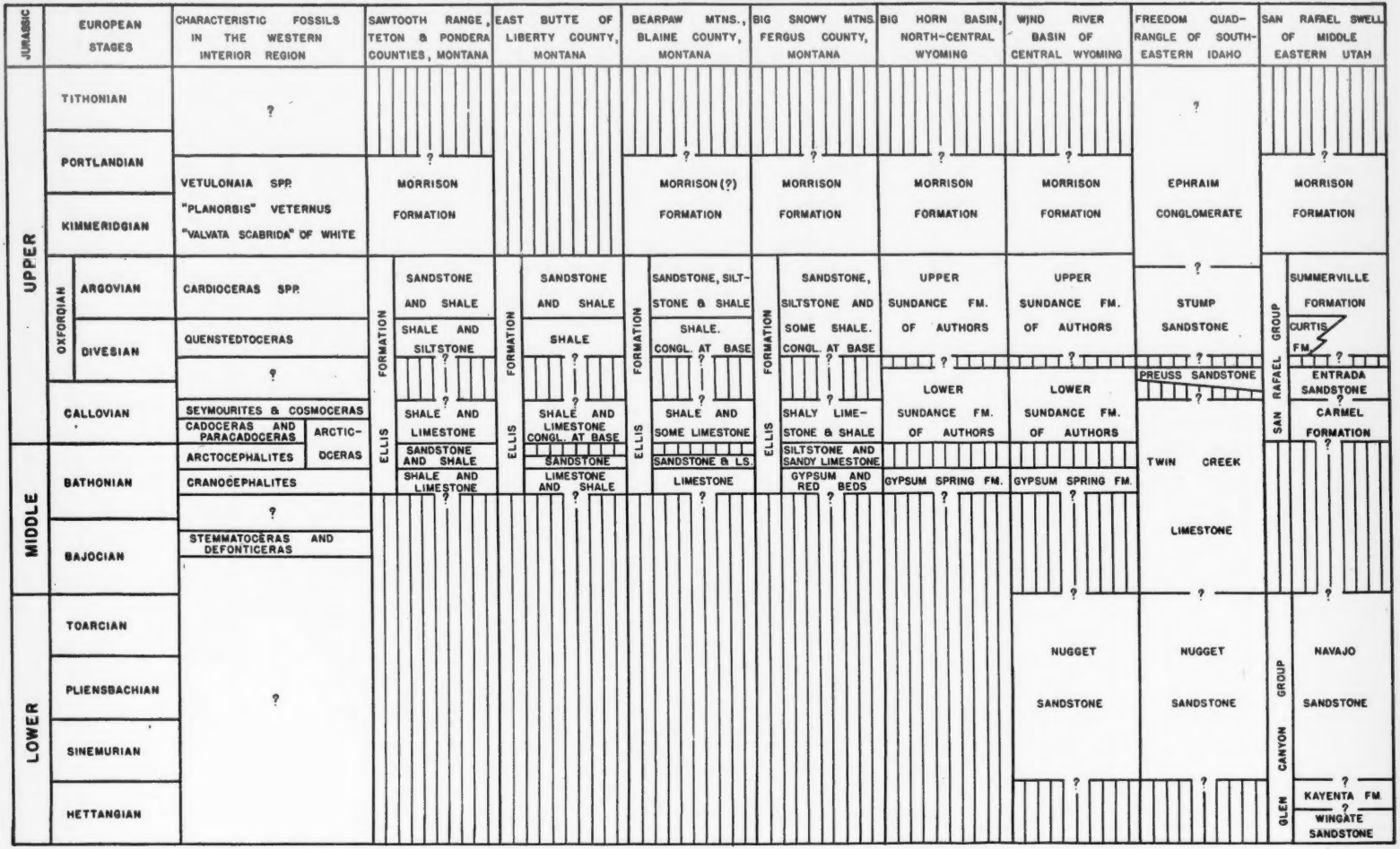
[4] Alpheus Hyatt, "Trias and Jura in the Western States," *Bull. Geol. Soc. America*, Vol. 5 (1894), p. 412.

[5] G. R. Mansfield, "Geography, Geology, and Mineral Resources of Part of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper 152* (1927), p. 98.

[6] C. H. Crickmay, "Study in the Jurassic of Wyoming," *Bull. Geol. Soc. America*, Vol. 47 (1936), p. 553.

TABLE I

Correlation of Jurassic Formations in Parts of Western Interior Region



examination of the United States Geological Survey's collections from Montana, Wyoming, Idaho, and Utah. These studies show that the marine Jurassic beds underlying the glauconitic sandy beds characterized by *Cardioceras* and *Quenstedtoceras* contain at least five ammonite zones, of which one is Bajocian, two are Bathonian, and two are Callovian (Table I). The ammonites and pelecypods of these zones are identical, or closely comparable with species described from Canada.[7] The paleontologic succession above the Bajocian is remarkably similar to that in Jameson Land, East Greenland.[8] Fortunately, in Montana the conditions of rock exposure and fossil preservation are so excellent that lithologic facies and faunal zones can be traced with confidence over large areas, permitting accurate determination of the faunal succession. These conditions are in contrast with those in the Fernie formation of Canada, where the succession of faunas has been determined mainly by comparisons with the European Jurassic.[9]

The oldest Jurassic faunal zone that has been discovered in the Western Interior region of the United States is from the Twin Creek limestone in the Freedom Quadrangle, southeastern Idaho. It contains *Stemmatoceras* cf. *S. albertense* McLearn, *Defonticeras* sp., *Camptonectes subbellistriatus* Warren, *C. albertensis* Warren, *Gryphaea impressimarginata* McLearn, and *Pentacrinus* sp. Some associated immature gryphaeas are probably identical with *G. cadominensis* Warren. This faunule undoubtedly represents the same time interval as that of the Rock Creek member[10] of the Fernie formation, which McLearn[11] and Crickmay[12] consider of middle Bajocian age and Spath[13] notes "is probably not later than upper Bajocian." The stratigraphic position of *Stemmatoceras* and *Defonticeras* within the Twin Creek limestone was not determined by the collectors but was estimated as approximately in the middle of the formation. Mansfield[14]

[7] S. S. Buckman, "Jurassic Ammonoidea, in Mesozoic Palaeontology of Blairmore Region, Alberta," *Geol. Survey Canada Bull. 58* (1929), pp. 1–27, Pls. 1–3.
C. H. Crickmay, "Fossils from the Harrison Lake Area, British Columbia," *National Museum Canada Bull. 63* (1930), pp. 33–113, Pls. 8–23.
F. H. McLearn, "New Pelecypods from the Fernie Formation of the Alberta Jurassic," *Roy. Soc. Canada Trans.*, Vol. 18, Sec. 4 (1924), pp. 39–61, Pls. 1–9.
———, "New Jurassic Ammonoidea from the Fernie Formation, Alberta," *Geol. Survey Canada Bull. 49* (1928), pp. 19–22, Pls. 4–8.
———, "Contributions to the Stratigraphy and Palaeontology of Skidgate Inlet, Queen Charlotte Islands, B. C.," *National Museum Canada Bull. 54* (1929), pp. 1–27, Pls. 1–16.
P. S. Warren, "A New Pelecypod Fauna from the Fernie Formation, Alberta," *Roy. Soc. Canada Trans.*, Vol. 26, Sec. 4 (1932), pp. 1–36, Pls. 1–5.

[8] L. F. Spath, "The Invertebrate Faunas of the Bathonian-Callovian Deposits of Jameson Land (East Greenland)," *Meddelelser om Grønland*, Bd. 87, Nr. 7 (1932), pp. 138, 145.

[9] F. H. McLearn, "Some Canadian Jurassic Faunas," *Roy. Soc. Canada Trans.*, Vol. 21 (1927), pp. 70, 71.
P. S. Warren, "Present Status of the Fernie Shale, Alberta," *Amer. Jour. Sci.*, Vol. 27 (1934), pp. 65–68.

[10] P. S. Warren, *op. cit.*, pp. 59, 66; *op. cit.* (1932).

[11] F. H. McLearn, *op. cit.* (1927), pp. 63, 68.

[12] C. H. Crickmay, "Jurassic History of North America: Its Bearing on the Development of Continental Structure," *Proc. Amer. Philos. Soc.*, Vol. 70, No. 1 (1931), p. 35.

[13] L. F. Spath, *op. cit.*, p. 11.

[14] G. R. Mansfield, *op. cit.*, structure sec. K–K''', Pl. 11.

shows the Twin Creek to be about 3,200 feet thick at a point 2¼ miles northwest. The occurrence of middle Bajocian ammonites some distance above the base of the Twin Creek limestone suggests that the underlying Nugget sandstone may be of Lower Jurassic age. Furthermore, the thickness of 1,500 feet, or more, attained by the Nugget sandstone in southeastern Idaho[15] and by its probable equivalent the Navajo sandstone in southwestern Utah,[16] suggests that these formations may account for the entire Lower Jurassic.

The next higher faunal zone that has been identified in the Western Interior region contains the ammonite *Cranocephalites*. It is overlain directly by a zone characterized by *Arctocephalites*. Both zones contain species of pelecypods belonging in McLearn's[17] *Corbula munda* faunule, which in Canada occurs 450 to 595 feet stratigraphically above the middle Bajocian Rock Creek member of the Fernie formation.[18] The ammonites in the *Corbula munda* faunule were described by Buckman[19] under several generic names and were considered by him to be Callovian, but Spath[20] places them all in *Arctocephalites* and considers them of upper Bathonian age. The *Cranocephalites* and *Arctocephalites* zones of the Western Interior region apparently correspond stratigraphically with zones dominated by the same ammonites in East Greenland,[21] and similarly are overlain by beds containing *Cadoceras*, *Paracadoceras*, and *Kepplerites* (*Seymourites*). In East Greenland these last three ammonite genera are reported to occur together, although the locality descriptions[22] suggest that fossils from different levels may have been mixed. Certainly in Montana the beds containing *Cadoceras* and *Paracadoceras* are stratigraphically 90 to 100 feet lower than the beds containing *Kepplerites* (*Seymourites*) and *Cosmoceras*. In East Greenland a zone characterized by an abundance of *Arcticoceras* occurs between the zones of *Arctocephalites* and *Cadoceras*, although *Arcticoceras* ranges into both the adjoining zones. In Montana, *Arcticoceras* occurs in the *Arctocephalites* zone and less commonly in the *Cadoceras* zone. A distinct zone characterized by *Arcticoceras* has not been recognized. An unconformity at about this position in the area east of the Sweet Grass arch is indicated by the *Cadoceras* zone's resting directly on the sandy *Arctocephalites* zone in the Big Snowy Mountains, Fergus County, and in the East Butte of the Sweet Grass Hills, Liberty County, and being marked basally at the latter locality by a limestone conglomerate. Also, an unconformity at the base of *Cadoceras* zone is widespread in Wyoming, where it marks the

[15] *Ibid.*, p. 97.

[16] A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., "Correlation of the Jurassic Formations in Parts of Utah, Arizona, New Mexico, and Colorado," *U. S. Geol. Survey Prof. Paper 183* (1936), p. 47.

[17] F. H. McLearn, *op. cit.* (1924); (1927), pp. 67, 68.

[18] P. S. Warren, *op. cit.* (1934), p. 67.

[19] S. S. Buckman, *op. cit.* (1929).

[20] L. F. Spath, *op. cit.* (1932), pp. 14, 33, 36.

[21] *Ibid.*, pp. 138, 143–46.

[22] L. F. Spath, *op. cit.*, pp. 126, 128, 131.

lower boundary of the "Lower Sundance" formation of current usage. However, in the Sawtooth Range of western Montana about 35 feet of calcareous shale, constituting the lower part of unit 13 of Deiss' section[23] at the head of Rierdon Gulch, has not furnished ammonites and may correspond with the *Arcticoceras* zone of Greenland.

The widespread development of the zones of *Kepplerites* and *Cadoceras* with perhaps a still older zone of *Arcticoceras* seems sufficient to account for lower and middle Callovian time and tends to confirm Spath's contention that the zones of *Cranocephalites* and *Arctocephalites* are of upper Bathonian age. In support of this age assignment he notes[24] that macrocephalitids appear in abundance late in the Bathonian, that *Arcticoceras* was not dominant before the lower Callovian, and that the still younger beds with *Cadoceras* and *Kepplerites* (*Seymourites*) represent both the lower and middle Callovian. Against Spath's age assignment is Crickmay's[25] report of the occurrence of the ammonite *Proplanulites*, a genus considered definitely Callovian, in the lower part of the Ellis formation of the Yellowstone National Park area. Detailed studies by the writer of the rich ammonite faunas from Montana, now in progress, should make possible exact age determinations of the various zones. The writer adopts here the age assignments made by Spath as being substantiated by more evidence than those made by Buckman.

The *Cranocephalites* zone in Montana occurs in the lowest part of the Ellis formation. It is represented in the Sawtooth Range mainly by black shale, in the Sweet Grass Hills by black shale and limestone, in the Bearpaw Mountains by black limestone, and in much of south-central Montana by gypsiferous beds associated with maroon siltstone and shale and some limestone. The Gypsum Spring formation of the Bighorn and Wind River basins of Wyoming appears to occupy the same stratigraphic position as the *Cranocephalites* zone of Montana.

The *Arctocephalites* zone in north-central Montana consists of silty to sandy shale and limestone, generally less than 50 feet in thickness, and very persistent in character over large areas. It appears to be absent in the Little Rocky Mountains, where the lowest beds of the Ellis formation contain *Cadoceras* and *Paracadoceras*. Its top is a disconformity in the East Butte of the Sweet Grass Hills. It has not been identified in the Bighorn and Wind River basins of Wyoming and is probably represented mainly by the unconformity at the top of the Gypsum Spring formation, as *Cadoceras* was obtained 15 feet above the Gypsum Spring formation two miles west of Cody on the west side of the Shoshone River. Also, in the Wind River basin fragments probably belonging to *Cadoceras* were obtained from the beds overlying the Gypsum Spring formation.

The faunas of the *Cranocephalites* and *Arctocephalites* beds may be illustrated

[23] Charles Deiss, "Structure of Central Part of Sawtooth Range, Montana," *Bull. Geol. Soc. America*, Vol. 54 (1943), p. 1137.

[24] L. F. Spath, *op. cit.*, pp. 138, 143–46.

[25] C. H. Crickmay, *op. cit.* (1936), p. 553.

by several sections in Montana. At Swift Reservoir at the head of Birch Creek, Pondera County, the ammonite *Cranocephalites* was obtained 20 feet above the base of the Ellis formation. The basal 2 feet of sandstone furnished among other species *Oxytoma blairmorensis* McLearn, *Trigonia* cf. *T. trafalgarensis* Warren, *Eumicrotis* n. sp. aff. *E. ferniensis* (McLearn), and *Astarte* (*Coelastarte*) n. sp. The *Astarte* occurs elsewhere in the basal member of the Ellis formation in East Butte of the Sweet Grass Hills, in the Bearpaw Mountains, and at Belt Creek about 9 miles south of Belt, Montana.

Examination of the lots submitted by Deiss from the Rierdon Gulch section[26] shows the presence of the *Corbula munda* fauna, as indicated below by the species attributed to McLearn. The collection from Deiss' zone 1, about 12 feet above the base of the formation, contains *Ostrea* sp., *Nucula* n. sp., *Trigonia montanensis* Meek, *Astarte meeki* Stanton, *Astarte* cf. *A. packardi* Meek, *Tancredia* sp., *Dentalium* sp., *Procerithium* (*Rhabdocolpus*) n. sp., *Pachyteuthis* sp. His zone 2, about 17 feet above the base, contains a *Tancredia* cf. *T. inornata* Meek. His zone 3, from 36 to 107 feet above the base, contains *Gryphaea* sp. juv. cf. *G. impressimarginata* McLearn, *Volsella rosii* (McLearn), *Lithophaga?* n. sp., *Protocardia schucherti* McLearn, *Pleuromya obtusiprorata* McLearn, *Tancredia* cf. *T. inornata* Meek, *Lucina* sp. His zone 4, the basal part of the *Arctocephalites* zone, about 107 to 120 feet above the base of the formation, contains *Ostrea strigilecula* White, *Arctica?* cf. *A. iddingsi* (Stanton), *Astarte meeki* Stanton, *Eumicrotis ferniensis* McLearn, *Camptonectes pertenuistriatus* Hall and Whitfield, *C. platessiformis* White, *Trigonia montanaensis* Meek, *Pleuromya obtusiprorata* McLearn, *Pholadomya kingi* (Meek), *Pinna kingi* Meek, *Protocardia schucherti* McLearn, *Grammatodon* n. sp., naticoid gastropod, and *Arctocephalites* sp. juv. His zone 5, about 160 feet above the base of the formation, contains *Pentacrinus asteriscus* Meek and Hayden, *Ostrea* sp., *Eumicrotis ferniensis* McLearn, *Astarte* cf. *A. packardi* Meek, *Camptonectes pertenuistriatus* Hall and Whitfield, *Pachyteuthis* sp. From silty limestone about 150 to 170 feet above the base of the formation the writer collected *Arctocephalites* and *Arcticoceras*. Deiss' zone 6, in the next overlying 38 feet, contains *Gryphaea impressimarginata* McLearn, *Corbula munda* McLearn, *Astarte meeki* Stanton, *Pleuromya obtusiprorata* McLearn, *Trigonia montanaensis* Meek, *Grammatodon* n. sp., and *Camptonectes* sp. An *Arctocephalites* was obtained by W. A. Cobban near the top of this unit. Deiss' zone 7, representing scattered collections from the next higher 108 feet of shale and limestone, contains *Gryphaea nebrascensis* Meek and Hayden, *Camptonectes pertenuistriatus* Hall and Whitfield, and *Pachyteuthis*. In addition, the writer found many large specimens of *Cadoceras* in these beds. It is apparent that Deiss' zones 1 to 3 represent the *Cranocephalites* zone, his zones 4 to 6 the *Arctocephalites* zone, and his zone 7 the *Cadoceras* zone.

The *Corbula munda* fauna is well developed elsewhere in the Sawtooth Range. However, the above record is sufficient to show that the pelecypods of the

[26] Charles Deiss, *op. cit.*, pp. 1137–39.

Cranocephalites and *Arctocephalites* zones consist in part of species characteristic of the silty to sandy *Corbula munda* beds in the Grassy Mountain section near Blairmore, Alberta,[27] and in part of species characteristic of the highly calcareous, shaly lower part of the Ellis formation in the Yellowstone National Park area.[28] The shales and limestones at the base of the Ellis formation in the East Butte of the Sweet Grass Hills and in the Bearpaw Mountains contain the common species found in the Yellowstone National Park area and none of the common species of the sandy *Corbula munda* beds.

Arctocephalites has been obtained at several localities in the Sawtooth Range and will probably be found at many places in the Western Interior region. It includes most of the species from the Yellowstone National Park area that were referred by Stanton[29] to *Oppelia*? sp. The zone of *Arctocephalites* is probably represented in the Twin Creek limestone of northern Utah, as a collection from a locality 12 miles west of Woodruff, south of Woodruff Park, Rich County, contains *Arctocephalites*? sp. juv., *Gryphaea impressimarginata* McLearn, and *Camptonectes pertenuistratus* Hall and Whitfield. *Ammonites henryi* Meek and Hayden[30] from the southwest part of the Black Hills is probably an *Arctocephalites*.

The Gypsum Spring formation has furnished a fairly large fauna of undescribed species unlike any of the published Jurassic faunas. A *Procerithium* (*Rhabdocolpus*) is very similar to a species in the basal limestone of the Ellis formation in the Bearpaw Mountains, Montana. A *Lucina* is similar to a species from the *Cranocephalites* beds in the Rierdon Gulch section of the Sawtooth Range, Montana. The species of *Nerinea* are unlike the forms in the Carmel formation of Utah. From a regional viewpoint, the Gypsum Spring formation appears to belong in the *Cranocephalites* zone, as similar gypsiferous deposits in the Big Snowy Mountains and adjoining areas of central Montana seem to grade into the *Cadoceras* beds through 20 to 35 feet of silty and sandy beds representing the *Arctocephalites* zone. If this correlation is correct, the Gypsum Spring formation is equivalent to the middle part of the Twin Creek limestone, and the unconformity at the top of the Gypsum Spring formation should gradually disappear westward.

The *Cadoceras* zone, because of its presence at or near the base of the Upper Jurassic and because it is one of the most fossiliferous zones in the Jurassic, promises to be extremely useful in selecting the boundary between Middle and Upper Jurassic rocks. It will undoubtedly be found in western Wyoming and in

[27] F. H. McLearn, *op. cit.* (1924).

[28] T. W. Stanton, "Mesozoic Fossils," in "Geology of the Yellowstone National Park," *U. S. Geol. Survey Mon. 32*, Pt. 2 (1899), pp. 600–32, Pls. 72–75.

[29] *Ibid.*, pp. 630, 631.

[30] F. B. Meek and F. V. Hayden, "Description of New Organic Remains Collected in Nebraska Terr. . . . ," *Proc. Acad. Nat. Sci. Philadelphia for 1858* (1859), p. 57;
———, "Palaeontology of the Upper Missouri," *Smithsonian Contri. Knowledge*, Vol. 14 (1865), pp. 123, 124, Pl. 5, Figs. 9a–c.

eastern Idaho, as a small ammonite from the Twin Creek limestone 2 miles east of Bear Lake, Rich County, Utah, is apparently an immature *Paracadoceras* resembling a species in the *Cadoceras* beds of Montana. Likewise, an ammonite from the basal 6 to 12 feet of the Carmel formation on The Wedge, about 2 miles south of Fullers Bottom along the San Rafael River, Utah, is nearly identical with an *Arcticoceras* in the *Cadoceras* beds of the Big Snowy Mountains of Montana and with *Arcticoceras kochi* Spath[31] from east Greenland. As *Arcticoceras* is not known below the *Arctocephalites* zone, its presence is excellent evidence that the Carmel formation is separated from the Navajo sandstone by an unconformity representing most of the Middle Jurassic.

The deepest part of the Jurassic trough until the end of the Callovian stage, as judged by the distribution, thickness, and ages of the rocks involved, extended northwest from central Utah, through eastern Idaho, westernmost Montana, and the boundary area of British Columbia and Alberta.[32] The axis of the trough lay west of the Sawtooth Range of Montana, considering that the oldest Jurassic beds exposed there belong to the *Cranocephalites* zone of the upper Bathonian, and that the still older marine Bajocian beds of southeastern Idaho must have had a connection northward through western Montana. The axis lay west of Blairmore, Alberta, as the oldest Jurassic rocks exposed there are of middle or upper Bajocian age,[33] whereas about 25 miles west, near Fernie, British Columbia, the base of the Fernie formation contains Lower Jurassic ammonites of the Sinemurian stage.[34] Marine Lower Jurassic is not definitely known south of the Fernie area, although a *Trigonia* has been reported from the basal part of the Nugget sandstone in the Wasatch Mountains.[35] Possibly Lower Jurassic fossils may yet be found in the lower part of the Twin Creek limestone, but this seems unlikely. In the Western Interior region of the United States marine waters appear to have been limited to the central part of the trough until late Bathonian, when they spread eastward across Wyoming and Montana, probably as far as the Dakotas. These waters were very shallow, and in central Montana, at least, were partially subdivided into basins by growing structures that now comprise the major structural features of that area. Thus from late Bathonian to Argovian times a string of islands existed along the site of the Little Belt Mountains and furnished considerable amounts of clastic sediments into the surrounding sea.

[31] L. F. Spath, *op. cit.*, pp. 55, 56, Pl. 12, Fig. 1; Pl. 13, Figs. 4, 5; Pl. 14, Figs. 1–3; Pl. 15, Figs. 1, 4–6.

[32] A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., *op. cit.*, pp. 55–58, Figs. 10–12.
F. H. McLearn, *op. cit.* (1927).
P. S. Warren, *op. cit.* (1934).

[33] P. S. Warren, *op. cit.*, p. 67.

[34] P. S. Warren, "A Lower Jurassic Fauna from Fernie, B. C.," *Roy. Soc. Canada*, Vol. 25, Sec. 4 (1931), pp. 105–11, Pl. 1.

[35] A. A. L. Mathews, "Mesozoic Stratigraphy of the Central Wasatch Mountains," *Oberlin College Lab. Bull.*, N. Ser., No. 1 (1931), p. 42.
Baker, Dane, and Reeside, *op. cit.*, pp. 6, 57.

The area of the Little Rocky Mountains appears to have been an island in the late Bathonian sea, as the *Cadoceras* beds were there deposited directly on Paleozoic limestone. The northward trending Sweet Grass arch formed a major barrier, east of which gypsiferous beds accumulated over thousands of square miles during part of the Bathonian. Perhaps a similar arch in western Wyoming separated the Bathonian gypsiferous beds of central Wyoming from the normal marine beds of the Idaho-Wyoming boundary area. Association of fossiliferous marine limestone with the gypsiferous beds shows that the barriers were not continuous and did not prevent incursions of marine waters from the west. The end of the Middle Jurassic, as herein interpreted by the *Arctocephalites* zone, was marked by uplift and erosion in central and north-central Wyoming, at least, and locally in Montana. However, throughout most of north-central Montana a thin mantle of silty to sandy calcareous beds was deposited. In places these beds appear to grade into the overlying highly calcareous shale and limestone of the *Cadoceras* zone and in other places to terminate disconformably, as in the East Butte of the Sweet Grass Hills.

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VOL. 29, NO. 7 (JULY, 1945), PP. 1028-1045, 3 FIGS.

GEOLOGICAL NOTES

IGNEOUS ROCKS FROM DEEP WELLS IN WEST TEXAS[1]

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It is becoming increasingly common for wells in West Texas to be drilled to the basement complex. As a consequence, opportunity to study these hitherto inaccessible rocks is increasing. It is believed that study of the petrography of these igneous and metamorphic rocks now made possible is a type of research which will not only result in contributions to the general knowledge but which may directly or indirectly be of benefit to the petroleum industry itself.

The present paper embodies the results of studies of well cores and cuttings from nine wells in West Texas. The locations of these wells are shown in Figure 1.

From six of these wells, cores were obtained for study. From the remaining three well cuttings only were obtained.

Special acknowledgment is due the Amerada Petroleum Corporation and the Stanolind Oil and Gas Company for samples and for permission to publish results.

In so far as possible, quantitative mineralogical studies and analyses were made of the various rocks. The classifications based on these analyses were made according to the Johannsen system of quantitative mineralogical classification.[3]

In computing the mineralogical composition of the rocks, use was made of a Wentworth improved recording micrometer. For the determination of such optical characters as the optic axial angle and determination of the feldspar, use was made of a Federoff universal stage.

CORE FROM AMERADA PETROLEUM CORPORATION'S KURFEES NO. 1
Sec. 6, H. and O. B. RR. Survey, Block N, Hale County, Texas

Megascopic.—The rock is medium-grained, showing abundance of dark-colored minerals and crystals of plagioclase feldspar.

Microscopic.—Texture is hypautomorphic-granular. Minerals are plagioclase feldspar, olivine, augite, serpentine, and magnetite. Euhedral crystals of apatite occur as an accessory mineral.

The plagioclase was determined to be labradorite.

The olivine is partly altered to serpentine and magnetite and shows charac-

[1] Manuscript received, April 4, 1945.

[2] Professor of geology, Texas Technological College.

[3] Albert Johannsen, *A Descriptive Petrography of the Igneous Rocks*, Chapter XIV, pp. 141–61. University of Chicago Press (1939).

teristic alteration along the cleavage cracks. The optic angle was measured and was found to be $2V=89°$. The maximum birefringence was determined to be 0.037.

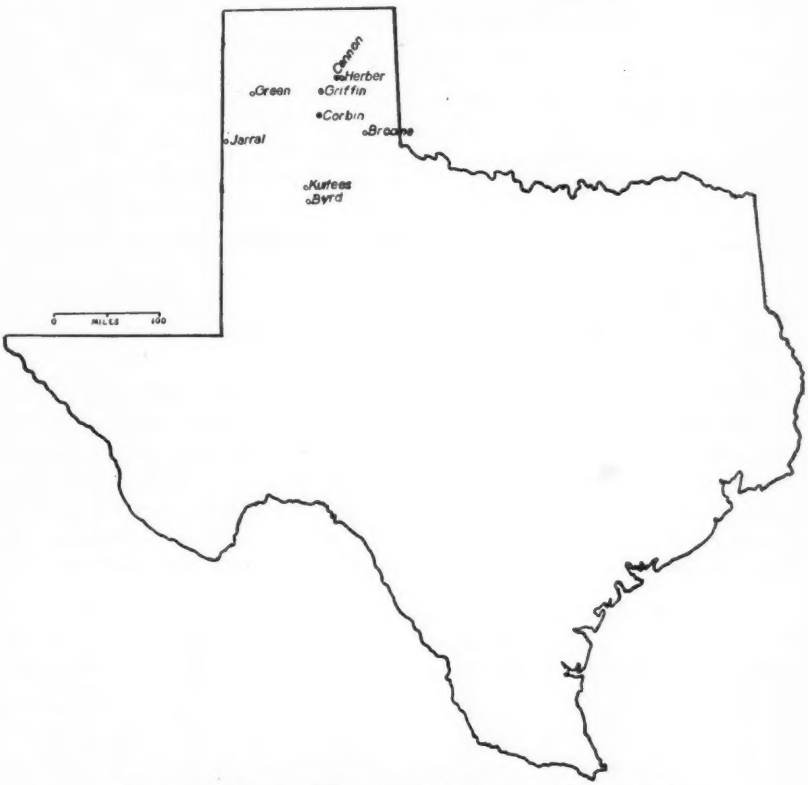


FIG. 1.—Sketch map of Texas showing locations of wells from which cores and cuttings described in this paper were taken.

ROSIWAL ANALYSIS

Traverse	*Labradorite*	*Augite*	*Magnetite*	*Olivine and Serpentine*
1	9.190	0.935	0.000	2.800
2	9.605	0.415	0.030	2.605
3	8.850	0.325	0.920	4.050
4	8.015	1.195	0.765	4.660
5	9.085	1.090	1.100	4.020
6	12.220	0.030	0.425	2.200
7	10.824	0.135	0.255	3.150
8	10.005	3.550	0.000	4.405
9	7.215	0.990	0.755	2.600
10	9.810	0.120	0.140	3.810
Total	94.819	8.885	4.390	34.300

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Labradorite	66.6
Augite	6.2
Magnetite	3.1
Olivine and serpentine	24.2
	100.1

Leucocrates make up 66.6 per cent of total components.....Class 2
Plagioclase is labradorite.....Order 3
No quartz.....Families 9–12
Plagioclase, 100 per cent of feldspar.....Family 12
Rock number.....2312
Rock name.....Olivine gabbro

CORE FROM HUMBLE OIL AND REFINING COMPANY AND STANOLIND OIL AND GAS COMPANY'S A. F. BYRD NO. 1

Sec. 17, T. and D. RR. Survey, Block K, Hale County, Texas. Depth 6,760 Feet

Megascopic.—The rock is phaneritic, medium-grained, showing crystals of pink feldspar and black amphibole.

Microscopic.—The texture of the rock is hypautomorphic-granular. The minerals are quartz, showing numerous minute inclusions, green hornblende, orthoclase, a small amount of oligoclase. A small amount of apatite is present as an accessory mineral. Other accessory minerals are magnetite and hematite which are scattered throughout the slide. The hornblende has characteristic amphibole cleavage, and extinction angle of $c \wedge z = 11°$ and a maximum birefringence of 0.022. The optic axial angle as determined by Universal Stage methods is $2V = 55°$.

ROSIWAL ANALYSIS

Traverse	*Quartz*	*Alkali Feldspar*	*Hornblende*	*Magnetite Hematite*	*Oligoclase*
1	3.250	4.335	3.900	1.540	3.035
2	4.630	3.560	8.465	0.225	0.000
3	1.375	3.820	7.375	0.150	0.000
4	0.395	3.255	5.980	0.000	2.430
5	2.330	5.575	3.290	9.250	0.000
6	4.400	1.685	2.590	0.825	1.435
7	7.630	2.015	0.415	0.000	0.000
8	5.095	3.120	3.915	0.155	0.000
9	4.435	8.350	3.605	0.000	0.000
10	3.680	6.610	6.685	0.000	0.000
Total	37.220	42.325	46.220	3.145	6.900

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Quartz	27.3
Alkali feldspars	31.1
Hornblende	33.9
Magnetite and hematite	2.4
Oligoclase	5.1
	99.8

Leucocrates make up 65.3 per cent of total components.....Class 2
Plagioclase is oligoclase.....Order 1
Quartz, 47.2 per cent of quarfeloids.....Families 5–12
Plagioclase, 16.8 per cent of feldspars.....Family 6
Rock number.....226 P
Rock name.....Hornblende granite

CORE FROM STANOLIND OIL AND GAS COMPANY'S GREEN NO. 1
Sec. 36, League 320, Block H-2, Oldham County, Texas

Megascopic.—The texture is phaneritic. The rock consists of crystals of pink feldspar with fewer crystals of quartz.

Microscopic.—The minerals are quartz, orthoclase, small amount of green hornblende, and small amounts of magnetite, and hematite. Micrographic intergrowths of quartz and orthoclase are common.

ROSIWAL ANALYSIS

Traverse	*Quartz*	*Alkali Feldspar*	*Hornblende*	*Dark Accessories*
1	2.280	8.235	0.950	0.105
2	2.490	9.090	0.230	0.060
3	3.470	8.225	0.000	0.065
4	3.685	7.445	0.080	0.025
5	2.780	8.385	0.240	0.248
6	2.715	9.215	0.510	0.030
7	2.900	9.030	0.490	0.115
8	2.605	8.110	0.455	0.000
9	2.655	7.350	0.000	0.150
10	3.480	8.650	0.000	0.235
Total	29.060	83.735	2.955	1.233

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Quartz	24.9
Alkali feldspars	71.5
Hornblende	2.5
Dark accessories	1.1
	100.0

Leucocrates form 96 per cent of total components.....Class 1
No plagioclase.....Order 1
Quartz, 25.8 per cent of quarfeloids.....Families 5–8
Alkali feldspars 100 per cent of total feldspars.....Family 5
Rock number.....115 P
Rock name.....Kalialaskite

CORE FROM STANOLIND OIL AND GAS COMPANY'S CORBIN NO. 1
Sec. 275, H. and G. N. Ry., Block B-4, Armstrong County, Texas.
Depth 6,118–6,119 Feet

Megascopic.—The groundmass of the rock is dense, of a pink color, and contains numerous small light-colored phenocrysts.

Microscopic.—The texture is holocrystalline, hypautomorphic with a microcrystalline groundmass. Numerous subhedral phenocrysts of alkali feldspar and

plagioclase feldspar and a very few small crystals of biotite. Groundmass consists of minute crystals too small for determination. Classification inferred from the following Rosiwal analysis of the phenocrysts.

ROSIWAL ANALYSIS

Traverse	*Alkali Feldspar*	*Oligoclase*	*Biotite*
1	3.290	1.260	0.000
2	1.865	0.400	0.000
3	0.125	1.550	0.000
4	1.790	2.575	0.000
5	0.830	1.790	0.000
6	1.605	1.605	0.000
7	3.255	1.040	0.000
8	2.975	1.925	0.000
9	3.425	1.750	0.000
10	4.695	1.665	0.415
Total	23.860	15.560	0.415

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Alkali feldspar	60.0
Oligoclase	39.2
Biotite	1.2
	100.2

Leucocrates make up 99 per cent of total components.....Class 1
Plagioclase is oligoclase.....Order 2
No quartz.....Families 9–12
Alkali feldspar, 60.6 per cent of total feldspars.....Family 10
Rock number.....1210
Rock name.....Leucotrachyte

SAMPLE OF CUTTINGS FROM HAGY, HARRINGTON, AND MARSH'S HERBER NO. 3
Sec. 184, H. and G. N., Block B-2, Gray County, Texas. Depth not Given

The section is made of pieces approximately 1 to 2 millimeters in diameter. There are 75 to 100 pieces on the slide used.

Microscopic.—Minerals identified are orthoclase, microcline, quartz, plagioclase feldspar, and a very small amount of green biotite. The plagioclase was determined to be oligoclase. Some of the fragments show micrographic intergrowths of quartz and orthoclase. The composition of the rock from which the fragments were derived is inferred from the following Rosiwal analysis. Measurements were taken across each fragment in the field, and a new field was taken for each traverse.

ROSIWAL ANALYSIS

Traverse	*Quartz*	*Alkali Feldspar*	*Oligoclase*	*Biotite*
1	2.425	6.885	3.410	0.000
2	2.545	2.960	1.140	0.000
3	3.060	6.730	5.110	0.000
4	1.375	10.105	0.180	0.180
5	3.240	7.620	0.250	0.000
6	5.965	6.560	0.450	0.220
Total	18.615	40.860	10.740	0.400

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Quartz	26.6
Alkali feldspar	57.4
Oligoclase	15.5
Biotite	0.6
	100.1

Leucocrates make up 99.4 per cent of total components.....Class 1
Plagioclase is oligoclase.....Order 2
Quartz 26 per cent of total quarfeloids.....Families 5–8
Alkali feldspar 77.6 per cent of total feldspar.....Family 6
Rock number.....126
Rock name.....Leucogranite

Since biotite is a mineral which is very easily lost from sample cuttings, it is possible that the original rock had sufficient biotite in it to put it into Class 2 instead of Class 1, giving it the rock number 226, a normal granite.

CORE FROM STANOLIND OIL AND GAS COMPANY'S BROOME NO. 1
Sec. 46, H. G. and N. RR., Block 20, Donley County, Texas. Sample from Depth 6,749 Feet. Total Depth 6,756 Feet

Megascopic.—The rock is phaneritic, medium-grained, having crystals of pink feldspar, quartz, and dark hornblende.

Microscopic.—The texture is hypautomorphic-granular. The minerals are orthoclase, quartz, green hornblende, partly altered to chlorite and a small amount of oligoclase. Accessory minerals are a few euhedral crystals of apatite and a small amount of magnetite.

ROSIWAL ANALYSIS

Traverse	*Quartz*	*Alkali Feldspar*	*Hornblende*	*Oligoclase*	*Magnetite*
1	0.950	11.745	0.590	0.000	0.000
2	2.105	8.375	2.570	0.285	0.360
3	2.415	9.485	2.015	2.390	0.575
4	0.045	5.915	3.935	0.780	0.420
5	3.190	8.155	1.800	0.220	0.255
6	5.290	5.950	0.935	0.000	0.000
7	4.200	13.150	1.890	0.000	0.505
8	3.185	11.855	3.270	0.000	0.000
9	5.305	11.990	0.645	1.695	0.000
10	5.220	11.905	1.415	0.000	0.000
Total	31.905	98.525	17.085	5.370	2.115

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Quartz	20.6
Alkali feldspars	63.5
Hornblende	11.0
Oligoclase	3.5
Magnetite	1.4
	100.0

Leucocrates form 87.6 per cent of total components.....Class 2
Plagioclase is oligoclase.....Order 2
Quartz is 23.4 per cent of quarfeloids.....Families 5–8
Plagioclase 6.3 per cent of total feldspars.....Family 6
Rock number.....226 P
Rock name.....Granite

CORE FROM STANOLIND OIL AND GAS COMPANY'S GRIFFIN NO. 1

Sec. 9, A. B. and M. Survey, Block 2. Carson County, Texas. Core from Depth 5,613–5,614 Feet. Total Depth 5,648 Feet

Megascopic.—A light-colored pinkish, aphanitic rock showing small phenocrysts.

Microscopic.—The texture is porphyritic with granophyric groundmass. The groundmass contains numerous spherulitic and plumose forms. Flow lines are distinctly visible. The groundmass contains a small amount of dark accessories. The pheonocrysts consist of subhedral crystals of quartz and a few crystals of andesite. The section also shows a few small pieces of biotite.

No quantitative mineralogical analysis was made because of the fineness of the groundmass. The general characteristics of the rock, however, are those of a granophyre. Because of the rather numerous spherulites of the groundmass the rock is classified as a spherulitic granophyre.

SAMPLE FROM HAGY, HARRINGTON, AND MARSH'S CANNON NO. 1

Sec. 237, H. and G. N. Survey, Block B-2, Gray County. Depth 3,102–3,109 Feet

The sample consists of small cuttings only. These consist mainly of a pinkish feldspar, with some crystals of quartz and biotite.

Microscopic.—Thin sections of the cuttings show the minerals to be orthoclase, microcline, oligoclase, quartz, and biotite. The potash feldspar shows some perthitic intergrowths.

No quantitative mineralogical analysis was attempted, but the composition of the rock is evidently that of a granite.

SAMPLE FROM STANOLIND OIL AND GAS COMPANY'S JARRAL NO. 1

Sec. 19, Capitol Land Survey, Block B, Parmer County, Texas. Depth not Given

Megascopic.—A light-colored aphanitic rock with small phenocrysts. Banded structure is due to flowlines distinctly visible.

Microscopic.—Texture hypocrystalline, porphyritic. Groundmass of microlites with some isotropic glass. Microlites show sub-parallel arrangement and bend around the phenocrysts in well defined flowlines, giving the rock a trachytic texture. Phenocrysts of andesine and potash feldspar. Some phenocrysts of biotite, considerably altered, and greenish in color.

No quantitative mineralogical analysis was undertaken, but the composition indicated is that of a trachyte or trachyte-andesite.

GEOLOGICAL CALENDAR[1]

(INDICATIONS OF PERIODICITY IN NATURE AND SUCCESSION OF GEOLOGICAL PERIODS)

MAXIM K. ELIAS[2]
Lincoln, Nebraska

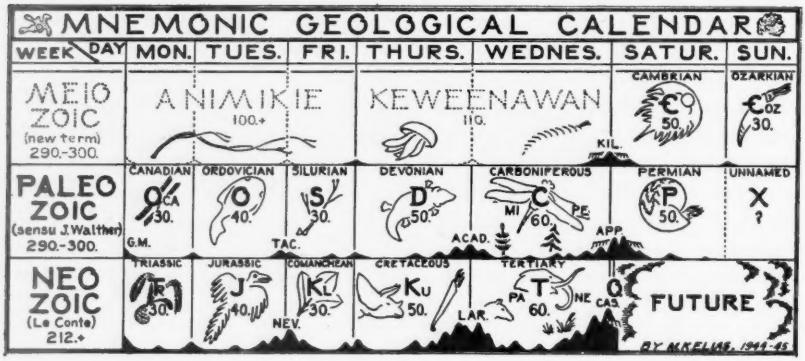
The problem of periodicity or rhythm in the history of the earth has intrigued many distinguished geologists, particularly in America. It is naturally so because in this "type-continent," the most complete earth's sedimentary record has been uncovered and some of the most interesting cases of cyclic repetition and rhythm in the rock formations have been observed and carefully analyzed. Newberry, Gilbert, Chamberlin, Ulrich, Schuchert, Barrell, Udden, Grabau, and many others discovered apparent regularities of various magnitude in the ancient marine transgressions, major orogenies, cyclic changes in sedimentation, and other historico-geologic phenomena. Most of these great men of American geology firmly believed in the cyclic nature of global orogenies and the principal marine transgressions and regressions connected with them, while only a few of their contemporaries vigorously disputed the existence of the world-wide simultaneity of the major marine inundations and orogenic events. Notwithstanding these differences in opinion all geologists agree on a division of geological time into periods of the same order of magnitude, but not necessarily of equal duration. Although selection of exact boundaries between the sedimentary systems, which correspond with the geological periods, and even the very existence of some of them (particularly as of period or system rank) are still intensely disputed, the relative position, extent and organic life of most of the periods are substantially agreed upon and their sediments have been correspondingly classified on both geological and paleontological grounds in all parts of the world. It is also universally agreed that the successive geological periods are divided by orogenies, yet it is also agreed that these intra-periodic orogenies vary greatly among themselves in both vertical amplitude and areal extension, and, besides, many more inter-periodic orogenies exist, which are, at least locally, about as strong as those which divide the periods. These facts complicate considerably the problem of the classification of all geological formations of the world into a single chronological sequence within a frame of universally accepted succession of a definite number of geological periods. Attempts at visualizing a much too great uniformity in either (1) duration of time covered by each geological period, or (2) regularity of their arrangement in equal groups (by Ulrich in 1911; Grabau in 1936, for 1933; and others) did not gain recognition among their colleagues. Nevertheless, theirs

[1] Manuscript received, April 7, 1945.

[2] Paleontologist, Nebraska Geological Survey, University of Nebraska. The geological calendar is being published here for the first time, but it was distributed as a New Year's greeting card to friends and colleagues in December, 1944. The writer is indebted to his colleagues, G. E. Condra and E. C. Reed, for reading the manuscript and for useful editorial suggestions.

are noble and stimulating attempts to express the apparently existing orderliness, even if difficult to detect, which underlies the geological history of our planet.

Virtually all geologists who ventured to calculate the duration of the geological periods concluded that the time covered by each period is far from equal, but different figures were obtained for both absolute and relative durations for the same periods by different authors, or even by the same authors at different times: compare the estimates by Sollas (1909), Schuchert (1910), Barrell (1917), Reeds



(1931), Moore (1933), Schuchert and Dunbar (1933 and 1941), Stille (1935), Croneis and Krumbein (1936), Twenhofel (1935), and others. In the constructed "Geological Calendar" the inequality of duration of the geological periods is accepted as one of the most important and well substantiated geological inferences. However, there seems to be good evidence, as discussed in the following paragraphs, for a conclusion that the inequality in the duration of the periods is not haphazard but has a definite pattern or orderliness, which is expressed in repetition of the same or nearly the same durations at regular intervals of time. This orderliness seems to emphasize the existence of a grand periodicity in the history of the earth, possible causes of which are as yet only dimly perceived: see the ideas and discussions by Holmes, Jolly, Coleman, Haarmann, Bucher, Lane, and others.

The major glaciations and the evidence of the "crescendoes" of the major orogenic epochs, which has been recognized by the Yale geologists and paleontologists Barrell, Lull and Schuchert, stand in definite relationship to each other, and seem to provide the main control for the arrangement of the inequal, but nevertheless cyclic, geologic periods into a periodic system, which may be expressed in the form of a "Geological Calendar." Its "days" are the geological periods and its "weeks," the grouping of the periods into eras. It seems clear that the inequality of the successive "days" in one geological "week" compares well with the same or nearly the same characteristic inequality which is displayed by the correspond-

ing successive "days" in another "week" (a relationship foreseen in a general way by Barrell, 1917, pp. 888–889). For instance, Silurian is decidedly shorter than Devonian, as most estimates of their durations indicate, just as Comanchean (when recognized as a separate period from the Cretaceous, is much shorter than Cretaceous proper, or Upper Cretaceous; Carboniferous is longer than either Silurian or Devonian, just as Tertiary is longer than either Comanchean or Cretaceous (Upper Cretaceous); and so on. Generally there is lesser agreement on the relative durations of Jurassic, Triassic, and Permian, as well as of Ordovician, Canadian, and Cambrian (with or without Ozarkian), the calculations of which are complicated by the disputes on correlations, boundaries, and recognition or rejection of one or another of these periods.

The following is the outline of the two methods by which the relative and absolute durations for each period, as indicated on the "Calendar," have been estimated. In the first method the known maximum thicknesses for the Paleozoic systems were expressed in the total thicknesses of the precipitated limestone based on the latest revisions of either directly measured limestone and dolomite sections, or clastic sections reduced to limestone (as recommended by Ulrich, 1911). The durations in millions of years were obtained by the division of these thicknesses by 140 feet. This latter figure was obtained by the division of the total thickness of the Paleozoic sediments (minus Upper Permian) "reduced to limestone," as summarized by Ulrich (1911, p. 381), over the corresponding total number of years based on the best available controlling figures calculated by the uranium-lead method. For the Tertiary the generally agreed figure of 60,000 years was taken (based on several uranium-lead analyses), while the particular figures for the Mesozoic periods of time were selected from published ones by various geologists, with preference to those which indicate that Jurassic is longer than Triassic, and Cretaceous longer than Comanchean, because this is also the present writer's view based on his own studies of the sediments of these ages in the area around Vladivostok, U.S.S.R. (Triassic and Jurassic), and in the Midwest of the U.S.A. (Comanchean and Cretaceous). An independent, second list of figures for the same periods was obtained by averaging some of the more recently published estimates of their duration as follows: by Barrell (1917, minimum), Schuchert and Dunbar (1933 and 1941), Moore (1933), Twenhofel and Schrock (1935), and Croneis and Krumbein (1936). Most of the figures for the Paleozoic periods obtained by these two methods, were in fair agreement (Table I); but when they were not, as for instance, the figures for the duration of the Permian, preference was given to the present writer's estimates based on maximum thickness of the rocks.

At this stage of the work it was observed that the figures for the duration of the periods in corresponding positions on either side of the major glaciations—Pleistocene, Permo-Carboniferous, and early Cambrian—tend to be equal. This observation prompted the attempt to arrange the periods in successive linear groups, one above the other, with the major glaciation in each placed on about the

same vertical line. As the periods, expressed in uniform time scale, began to fall in line, in respective position, one above the other, an almost perfect correspondence was found in their time durations in each linear group, provided that (1) the Mississippian is united with the Pennsylvanian to form the Carboniferous, the latter being about equal in duration to the Tertiary, (2) the Canadian is separated

TABLE I

ESTIMATES OF RELATIVE AND ABSOLUTE DURATIONS OF GEOLOGICAL PERIODS AND SUB-PERIODS IN MILLIONS OF YEARS, BASED ON THICKNESSES OF SEDIMENTS ADJUSTED TO SELECTED TIME FIGURES OBTAINED BY LEAD-URANIUM METHOD

Sources and Nature of Estimates / *Periods and Sub-Periods*	1	2	3	4	5	6	7	8	9	10	11
	Barrell, Minimum	*Schuchert and Dunbar*		*Moore*	*Twenhofel*	*Croneis and Krumbein*	*Average from Six Estimates*	*New Estimate*	*Calendar Figs.*	*More Nearly Correct Round Figs.*	*Round Figures Reduced 10%*
	1917	1933	1941	1933	1935	1936	1945	Elias, 1945			
Neogene	18	25	17	58	60	28	22	60	60	60	54
Paleogene	36	35	43			30	36				
Cretaceous	40	50	35	65	60	70	42	45	50	45	41.5
Comanchean	25	30	20				25	30	30	30	27
Jurassic	35	35	40	32	40	38	37	40	40	40	36
Triassic	35	25	35	28	40	32	32	35	30	30	27
Permian	25	40	30	38	30	35	33	46	50	45	41.5
Pennsylvanian	35	40	30	48	50	45	43	29	60	60	54
Mississippian	40	30	30	38	35	35	35	34			
Devonian	50	40	40	45	40	35	42	43	50	45	41.5
Silurian	40	30	30	27	30	25	30	27	30	30	27
Ordovician	90	70	60	67	50	70	68	41	40	40	36
Canadian								30	30	30	27
Ozarkian	70	90	80	105	50	105	83	30	30	30	27
Cambrian								48	50	45	41.5
TOTAL	539	550	490	551	485	548	548	538	550	530	472

from Ordovician, the duration of each, thus divided, becoming nearly equal to that of the Triassic and Jurassic, correspondingly, and (3) the Ozarkian is separated from the Cambrian, the duration of the latter becoming near that of the Permian. The last conclusion revived in memory Grabau's conviction of an existence of a period-like time interval between Permian and Triassic. Probably here belong the terrestrial Karoo system of South Africa and the terrestrial Russian "Eotriassic." This hypothetical time interval falls in a place corresponding with Ulrich's Ozarkian. Both occur at the end of geological eras—if Cambrian (and Ozarkian) be removed from the Paleozoic, as suggested by Johannes Walther, and Mesozoic and Cenozoic are united into a single era, as suggested by Le Conte. The writer then rebuilt his linear groups of geological periods into a calendar-like table with eras corresponding with successive rows

of "weeks," each "day"-square of which corresponding to a geological period. In this first verion of the "Geological Calendar" the figures of durations of the periods are entered in millions of years. In all of these operations the horizontal scale is preserved to represent the period durations, so that the major orogenies could be shown in their proper respective positions and intensities. Because the time-scale is kept it is possible to see that the width of each rectangle can be easily made exactly equal to that in one above or below it by only a slight change in the durations; thus, it was naturally decided to modify them so as to obtain more nearly round figures. In this the general practice of geologists was followed because the estimates of durations by any methods now available give only rough approximations, with probable errors at best measured in a few million years.

At this stage of the work it was also noticed that a mnemonic rule can be introduced, where, by pure coincidence, the number of letters in the name of a day (minus the word "day") corresponds with the approximate number of years in tens of millions in a geological period, starting with *Monday* as first day, and interchanging *Wednesday* and *Friday* in a "Geological Week." Thus, it was decided to round the figures to even tens of millions, with a tendency to increase rather than to reduce them. For instance, the figures of 45 for Cretaceous, 46 for Permian, and 43 for Devonian were enlarged to 50, these being the largest departures from the originally calculated figures. More nearly accurate estimates would be 45 million years for each, as shown in column 10 of Table I.

The foregoing outlined methods used in these calculations and checks of the relative and absolute durations for the geological periods, in which the data were used from publications 8 or more years old, necessitated adherence to controlling figures obtained by the uranium-lead method earlier in this century, and not the recalculated latest ones, obtained in the last few years. Should these latest controlling figures have been used it would have reduced the estimated duration of geological time somewhat below the minimum figures which were given by Barrell in 1918, and which many geologists still consider most acceptable. Totaling the years shown on the "Geological Calendar" (Table I) shows that they are only slightly above the corresponding totals for Barrell's minimum figures, and are much below his maximum figures. To bring the round figures of the Calendar into accord with the latest published control figures based on improved lead-uranium calculations, they should be reduced about 10 per cent each (column 9 in Table I).

The figures obtained at each step of the outlined procedures are tabulated in Table I. Some of the relative and absolute durations for various periods accepted here correspond closely with those frequently given in many modern geological professional papers, text-books, and the best popular accounts of the earth's history. The orogenies, which are shown in the "Calendar" are spaced in geologic time chiefly according to Stille (1924, 1935, and later publications), but their relative intensities, which are indicated by the heights of the blackened mountains, are largely after Schuchert and Dunbar (1933, 1941), with some additional consid-

eration given to the opinions by Stille (1935), W. Bucher (1933), and D. Mushketov (1935).

Previously there has been no definite criterion devised by which recognition of geological periods could be controlled, except that most geologists believed that a period begins with a major inundation of the continents and terminates with their general emergence, which view corresponds with the general understanding that periods are punctuated by more or less widespread orogenies. But the very same periods are also considered by Grabau (1936, for 1933) as being made each of two major sea transgressions and one intermediate regression, and of two major regressions and one intermediate transgression, alternately. The periodicity of the geological periods, as expressed in the geological calendar, and controlled by the combined evidence of the orogenic crescendoes, major glaciations, and similar character of inequality in the apparent duration of successive periods which precede and follow each major glaciation, seems to provide a desired control for recognition and delimitation of geological periods of time. If this grand periodicity exists, then it follows that (1) if we recognize Silurian as of period rank, the Comanchean period should be also so recognized; (2) if the Triassic and Jurassic are recognized as periods, the Canadian should be separated from Ordovician as a ranking period of time; (3) if Carboniferous be divided into two periods, Mississippian and Pennsylvanian, the Tertiary should be correspondingly divided into Paleogene and Neogene, as some geologists advocate; and so on. Perhaps most interesting and most disputed are the evidences left by two of the most critical moments in geological history, both falling at "Sunday" of the "Geological Week": Ulrich's Ozarkian which is about the most disputed of all geological periods, as most geologists correlate its sediments with the upper Cambrian (Croixian); and existence between Permian and Triassic of a time interval equal in magnitude to a period, as suggested by Grabau. If there was a "Geological Sunday," it seems that it was a time when only little and rather localized sedimentation took place, and naturally our knowledge of its life is rather scarce. It is generally conceded that many major groups of marine invertebrates disappeared abruptly at the close of Permian time and before the inauguration of the early Triassic marine transgression. Could some of them have survived into this problematic time interval? Correspondingly, there is a greater number of major groups of marine invertebrates which appear at the initiation of Ordovician than the number of groups which made their start at early Cambrian; some of them could have started in the Ozarkian, for instance, the cephalopods.

The grouping of the geological periods into grand cycles of six or seven periods in each supports the suggestion by LeConte to put Mesozoic and Cenozoic into a single era, which he designated the Neozoic. Similarly, it supports the separation of Cambrian from Paleozoic, which was suggested by Johannes Walther (1908), who pointed out that the end of the Cambrian was a more critical time in the development of the early marine life than the time immediately preceding the Cambrian. The critical character of the late Cambrian-early Ordovician time

interval in development of life is reflected on some charts which have been prepared to show initiation and maximum development of principal groups of marine animals in the Paleozoic (see Cleland's textbook of geology, and others). On the other hand some evidence was presented to show continuity in the character of sedimentary rocks and presumably of the life in the sea in the pre-Cambrian (Beltian) and Cambrian time in the area of the northern Rocky Mountains. The addition of Cambrian (and Ozarkian, if the latter is recognized as ranking period) to late pre-Cambrian suggests differentiation of another era of early marine life which seemingly includes Cambrian, Keweenawan, and Animikie. If the periodicity of eras is accepted, then the era immediately preceding the Paleozoic (*sensu* Walther) should be 250 to 300 million years in duration. Because the existing terms Proterozoic and Archeozoic have been used in a multitude of senses, but always including some strata below the Animikie, and never including the Cambrian, a new name is here suggested, Meiozoic (from Greek *meion*, less, meaning less animals) for this era.

The grand cycles in the history of the earth, which are indicated as "weeks" in the geological calendar seem to be controlled rather by the earth's inner processes, as the orogenic crescendoes seem to indicate, than by cosmic influences. But there are other cyclic phenomena which are apparently superposed over the grand cycles, which complicate and tend to obscure them. The truly cyclic nature of the grand cycles is indicated by the fact that any one of the successive geological periods can be selected as an initial point for a grand cycle, and different "weeks" can thus be constructed. For instance, if the time of most intense orogeny, accompanied by glaciation be selected for the division of eras, then Cambrian will initiate the Paleozoic era, but on the other hand Permian will have to be added to the Neozoic era. This latter arrangement has been advocated by some paleobotanists who point out that the late Carboniferous-early Permian was a much more critical time in the development of land plants than the late Permian-early Triassic time. But it seems, from a general geological point of view, that the times of initiation of Canadian and of Triassic periods are more convenient starting points for the grand cycles or eras, as they will correspond with the times following the maximum quietness of the geological "Sunday."

Comparison of the geological periods with the Days of Creation in *Genesis* is a subject which held the attention of some prominent geologists and clergymen a few decades ago. Some degree of analogy has been noted in the sequence of the Acts of Creation, as narrated in *Genesis*, and the sequence of geological periods and development of life, as revealed by geology, but many differences between the two have been also pointed out. However, this fascinating subject is left out of consideration in this article. The calendar-like form is here introduced merely to show the grand periodicity of the geological periods, and the comparison of periods and eras with days and weeks are introduced in order to facilitate memorizing the regularity in succession of the inequal periods and their relationship to the major orogenies and glaciations.

The earliest, pre-Meiozoic eras of geological history are not covered by the calendar because both the orogenies and the development of life, which permit classification of later geological time into periods, left only indistinct traces in the corresponding earliest sediments, the interpretation and classification of which are extremely difficult and uncertain. It seems possible that the earliest geological time, too, can be roughly divided into sub-equal grand cycles or eras to which the well known terms Azoic, Eozoic, and Archeozoic may be applied. Likewise, a phase of major refrigeration perhaps may be recognnized in each. However, these possibilities are beyond the scope of the present article, which is concerned only with Meiozoic, Paleozoic and Neozoic eras.

The symbols used in the mnemonic geological calendar are as follows. The large letters in the center of each rectangle of the calendar are the standard designations of the United States Geological Survey for the corresponding sedimentary systems, except that smaller capital letters were added, such as OZ to indicate Ozarkian, CA to indicate Canadian, MI and PE to indicate Mississippian and Pennsylvanian, and PA and NE to indicate Paleogene and Neogene. The abbreviated names of the orogenies are correspondingly, from earlier to later: Killarney, Green Mountains, Taconian, Acadian, Appalachian, Nevadian, Laramide, and Cascadian. The outline sketches of plants and animals, from one to three in each rectangle, indicate their first appearances: attached seaweeds in Animikie (possible); jelly-fishes in early Keweenawan (possible); segmented worms in late Keweenawan (possible); trilobites in Cambrian; cephalopods in Ozarkian; graptolites in Canadian; ostracoderm fishes in Ordovician; land plants in Silurian; amphibians in Devonian; horse-tails in early Carboniferous, insects in middle Carboniferous, and conifers in early Pennsylvanian (Central Colorado); ammonites (*Properrinites*, *Medlicottia*, and others) in early Permian, cycads in Triassic; toothed birds in Jurassic; dicotyledonous trees in Comanchean; *Triceratops* in Cretaceous and the uncoiled gerontic ammonites (*Baculites*) in late Cretaceous; primitive horse (*Eohippus*) in early Tertiary, elephants in the middle Tertiary (early Oligocene of Egypt), and prairie grasses in the early Neogene (early Miocene of the High Plains of the United States). At the top of the calendar is the conventional symbol of organic evolution: from amoeba to man.

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GRAPTOLITES ON WELL CUTTINGS, CARTER COUNTY, OKLAHOMA[1]

CHARLES E. DECKER[2]
Norman, Oklahoma

Graptolite fragments are well preserved on flakes of shale in cuttings from the well, Ideal, Scroggins No. 12 in the SW. ¼, SE. ¼, SE. ¼ of Sec. 32, T. 3 S., R. 3 W., Carter County, Oklahoma. The cuttings came from the interval from 1,225 to 1,328 feet. The total depth is 1,354 feet, and the surface elevation is 984 feet. The well was completed as a small producer in the Pennsylvanian in June, 1937.

Fragments of graptolites occurring on flakes of shale in these cuttings are shown in Figures 1 to 3. These fragments represent three species of graptolites characteristic of the Sylvan shale which, on evidence given by the writer,[3] was shifted from the Silurian to the Upper Ordovician. However, the most distinctive horizon marker, *Dicellograptus complanatus*, is not represented in the cuttings, unless it is by an elongate, slender fragment on which no thecae are preserved.

The graptolites all belong to the order *Graptoloidea*, and they include *Diplograptus crassitestus*, *Climacograptus mississippiensis*, and *Climacograptus putillus*.

[1] Manuscript received, May 7, 1945.

[2] Research professor in paleontology, University of Oklahoma.

[3] Charles E. Decker, "Graptolites of the Sylvan Shale of Oklahoma and Polk Creek Shale of Arkansas," *Jour. Paleon.*, Vol. 9 (1935), p. 702.

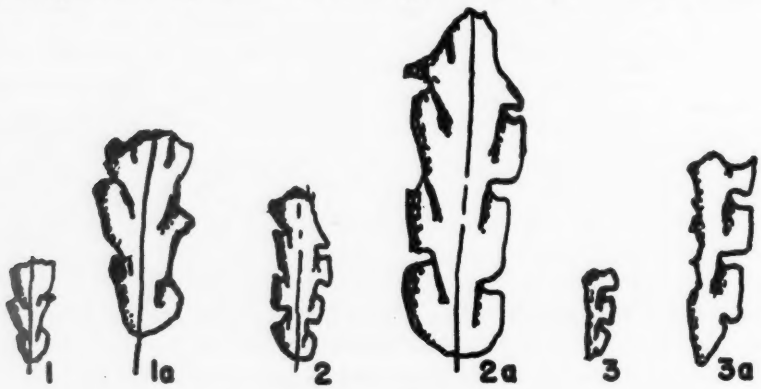
DESCRIPTION OF SPECIES

Genus DIPLOGRAPTUS McCoy 1854

Diplograptus crassitestus Ruedemann[4]

Figures 1, 1a

The thecal part of a normal colony is small, being 10 to 12 millimeters in length, though some specimens may attain a greater length. The fragment shown in Figures 1, 1a is less than 2 mm. long with a nemal thread extending nearly $\frac{1}{4}$ the length from the proximal end. This fragment represents about $\frac{1}{5}$ of a colony.



EXPLANATION OF FIGURES

(Figures 1, 2, 3 are magnified ×8 and 1a, 2a, 3a, ×16)

FIGS. 1, 1a.—*Diplograptus crassitestus* Ruedemann.
FIGS. 2, 2a.—*Climacograptus mississippiensis* Ruedemann.
FIGS. 3, 3a.—*Climacograptus putillus* (Hall).

It has a length of a little less than 2 mm., and a width varying from 0.5 to 0.75 min. The thecae characteristically turn back from the sicular end like sides of a steep trough, and the thecae are about 0.75 of a mm. in length. Most all of six thecae are preserved. This proximal fragment has about 12 thecae in 10 mm. which is characteristic of this smaller end of the species.

Diplograptus crassitestus is commonly associated with *Dicellograptus complanatus*, *Climacograptus mississippiensis*, and *Climacograptus putillus*, and they are found most abundantly in the lower part of the Sylvan shale of Oklahoma and the Polk Creek shale of Arkansas.

Genus CLIMACOGRAPTUS Hall 1865

Climacograptus mississippiensis Ruedemann[5]

Figures 2, 2a

The fragments shown in these figures have the rounded sicular or proximal

[4] Rudolf Ruedemann, "Graptolites of New York," Pt. 2, *New York State Mus. Mem.* 11 (1908), p. 354, text Figs. 299, 300, Pl. 25, Fig. 6.

[5] Rudolf Ruedemann, *op. cit.* (1908), p. 413.

end, the gradual increase in width, and the apertural marginal notches characteristic of this species, as well as the same thecal number of 12 in 10 mm. The fragment shown in the figures has a length of 3 mm. and a width of 0.75 to 1.25 mm. The apertural notches in this view have a depth of almost one-fourth the width of the stipe. The nemal thread extends slightly beyond the margin of the proximal end.

This species is found widespread in the lower part of the Sylvan shale of Oklahoma and the Polk Creek shale of Arkansas.

Climacograptus putillus (Hall)

Figures 3, 3a

Ruedemann[6] has described this species, has given 14 references in a synonomy, and has shown Hall's original illustrations of the species.

The tiny fragment shown in Figures 3, 3a has only one side of the proximal end of a stipe preserved, yet its characteristics strongly suggest that it belongs to this species. Members of this species are very small, less than 9 mm. in length with thecae short and close set, numbering 12 to 14 in 10 mm. If the nema is preserved, it shows a thin thread-like structure. The small fragment shown in Figure 3 has a length of 1.5 mm.

This species occurs in countless numbers in the lower part of the Sylvan shale, and it extends up through about 100 feet of the formation. It occurs also in the lower part of the Polk Creek shale of Arkansas and the Maquoketa shale of Iowa and Minnesota. While the species has been given much wider distribution, it has been confused with several small species of *Climacograptus*, so the evidence for such wide dispersal rests on an insecure foundation.

A former student sent the cuttings, and a request has been made that the information be presented anonymously. As the information seems thoroughly reliable, it is being presented to show that small fragments of graptolites having a length of 3 mm. or less may have characteristics distinctive enough to designate the species. Then an assemblage of them, as shown here, may identify the horizon and formation in which they were found. Such evidence is particularly important, when the physical characteristics of a formation varies laterally, as do those of the Sylvan shale, so that it becomes difficult to recognize it in some of these altered phases.

Then, too, the evidence presented here should encourage greater care in the study of cuttings which contain graptolite fragments, as the fragments may supply very significant information.

[6] Rudolf Ruedemann, *op. cit.* (1908), pp. 415–19, text Figs. 368, 369.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

VOLCANOES AS LANDSCAPE FORMS, BY C. A. COTTON

REVIEW BY BURTON WALLACE COLLINS[1]
Auckland, New Zealand

Volcanoes as Landscape Forms, by C. A. Cotton, Victoria University College, Wellington. 416 pp., 223 figs. Whitcombe and Tombs Limited, Christchurch, New Zealand (1944). Price 32s. 6d. (N. Z.)

In a recent letter to the writer, W. N. Benson, professor of geology at the University of Otago, Dunedin, New Zealand, referring to a paper on economic paleontology and stratigraphy, commented ironically that he was "not supposed to be interested in such matters"—implying, of course, that he was indeed very much interested. Such a remark might well be made also by the petroleum geologist in his professional capacity with reference to the subject matter of the book here reviewed. Most petroleum and other economic geologists retain, however, a lively interest in the more academic phases of the broad science of geology, and Professor Cotton's latest book should provide them with several hours of pleasant and stimulating reading if nothing more.

If excuses be needed, however, for bringing to the attention of petroleum geologists a book on the geomorphology of volcanoes, there are several to hand. The association of oil with volcanic rocks is not unknown. In New Zealand, indeed, the only commercial (or semi-commercial) accumulation of petroleum so far discovered—near the town of New Plymouth, on the west coast of the North Island—appears to be connected in some way with the volcanic (or hypabyssal) rocks of Paritutu Hill and the Sugarloaf Islands. (See the following review.) In other countries, also, notably Mexico, igneous rocks in the form of volcanic necks, dykes, and sills, have sealed beds in which oil has accumulated.

Secondly, active and only recently extinct volcanoes form prominent features of the landscape in many oil-producing and prospective oil-producing countries, especially those lying in or near the great circum-Pacific Tertiary geosynclinal belt—as, for instance, Central America, New Zealand, New Guinea, and the Netherlands East Indies.

And, thirdly, among an amazing number and variety of bibliographic references, Cotton in this book (pp. 291 and 316) quotes from two papers published recently in this *Bulletin*.

Having thus salved our consciences as petroleum geologists we may now proceed to consider the book. As the author states in his preface:

> For a book devoted to the geomorphology of volcanoes there is no precedent: no model work is available which may be followed in the setting out of the subject matter.

Few, however, will find fault with the manner in which the subject is here approached and treated. This is, indeed, volcanology made easy, for, again in the words of the preface,

> An approach to volcanism may be made through either petrology or geomorphology, a volcano and its mechanism being regarded either as a geological crucible or as a builder of landforms. In this book, after a few brief introductory chapters, the latter approach is adopted, and the book is frankly concerned with landforms of volcanic origin and with their geomorphic development rather than with theories of volcanism and petrogenesis.

And yet, although the petrological side is touched on but lightly, sufficient information

[1] P.O. Box 10, Auckland C1. Manuscript received, April 17, 1945.

is given on the composition, origin, and properties of the different products of volcanism to enable the reader to appreciate the various types of volcanic cones and other constructive landforms, as well as their widely divergent relative resistances to erosion.

In Part I, "The Mechanism of Volcanism" (pp. 1–69), there is presented with admirable clarity and simplicity a comprehensive review of modern theories of volcanic action. Such authorities as F. A. Perret and T. A. Jaggar (the book is dedicated to these two "volcanologists of this century"), R. A. Daly, H. T. Stearns, A. L. Day, E. T. Allen, and K. Sapper, are frequently quoted, and the footnotes (averaging two or three to the page) form an extensive bibliography to this aspect of the subject. The various types of eruptive activity and the resulting volcanic cones are described; an account is given of gas reactions and theories of origin of volcanic heat; Jaggar's terms, *hypomagma*, *pyromagma*, *epimagma*, and *bench magma*, are introduced and explained; and explosive activity and the building of pumice volcanoes, including the *nuée ardente* type of eruption, are fully discussed. This part concludes with a chapter on "Vesuvius and its Cycles of Activity," in which reference is made to the eruption of March, 1944.

It is in Part II, "Volcanic Landscapes," (pp. 70–401), however, that Professor Cotton makes his more original contributions. This section comprises the first extensive and relatively exhaustive treatment of the forms and erosional features of volcanic accumulations on the earth's surface. Beginning with the larger constructional landforms the chapters survey in turn all the major and most of the minor features of volcanic origin, the author illustrating his remarks by examples drawn from all over the world. As an indication of the exhaustive nature of the treatment and in order to give some idea of the arrangement of topics, the chapter headings follow: Domes and Cones of Basaltic Lava; Lava Plateaux and Plains; Lava Fields; Aa and Block Lava: Scoria Mounds; Viscid Lavas: Coulees and Tholoids; Ash Showers and *Nuées Ardentes;* Ash-built and Stratified Cones; Maars and Tuff Rings: Meteor Craters; Submarine Eruptions: Pillow Lavas; Craters and Calderas: Volcanic Depressions and Lakes; Dissected Basalt and Ignimbrite Plateaux: Basalt Plains; Erosion and Destruction of Volcanic Mountains.

It would be impossible in this review to give an adequate idea of the amount of material included, nor would it be possible to list Cotton's new contributions to geological thought. It must suffice to say that the discussion embraces nearly every active or recently active volcano and volcanic district in the five continents and the seven seas—from the puys of Auvergne to Lassen Peak, and from Bogoslof in the Aleutians to that jack-in-the-box, Falcon Island of the Tonga group. And the most valuable aspects of Cotton's work is not so much his original observations, as his collation of innumerable facts and opinions from a multitude of sources—British, American, German, Dutch, and Italian—and their presentation from a fresh angle and in a new light.

The earlier chapters of this part are naturally mainly concerned with the constructive aspect of volcanic action, though features arising from erosion are also incidentally mentioned. In the last three chapters especially, however, discussion of the work and results of the normal erosive processes finds a more important place, and many readers, especially geomorphologists, will find them the most interesting part of the book. In the last chapter of all, the section on the "Origin and Development of the Oahu Valleys" was, for the reviewer, the *pièce de résistance.* Concerning many of the points touched on in the few pages of this section, Professor Cotton would be the first to agree that the last word has by no means yet been said. The whole question of erosion under tropical conditions is involved in a discussion of this type, and the data on this subject are surprisingly meager. It is here that petroleum geologists, working in the little-known countries of the hot and wet regions of the earth, might well, by recording their observations, make a significant contribution to the science of geomorphology. Is it true, for instance, that

> These [an extremely heavy rainfall and rapid tropical weathering, as on Oahu] are the conditions under which generally concave valley-side slopes and knife-edge divides become the rule on almost every kind of terrain?

And statements such as the following, from a recent article[2] by the same author, though probably valid, need to be tested by competent observers.

> It may well be inferred, or at least strongly suspected, that theories of valley sculpture here developed [in the Hawaiian Islands] will be broadly applicable to the majority of rain-soaked hot regions with strong relief. . . .
>
> It may be suspected . . . that adjustment [of drainage to structure] is generally very imperfect . . . in regions of tropical jungle and rain forest.

Like its predecessors[3] in Cotton's series on various aspects of geomorphology, the present book owes much of its value and interest to its excellent illustrations—well chosen and well reproduced. Unlike them, however, the book is printed throughout on coated paper and the illustrations (photographs, maps, sketches, and block-diagrams) are distributed through the text. In the opinion of the reviewer this is a definite improvement. The placing of bibliographic references in footnotes to each page—a feature common to all three books—has disadvantages, and many would have preferred them collected in alphabetical order of authors either at the end of the book or at least at the end of each chapter.

The book is remarkably free from printer's errors and typographical inconsistencies. A few page numbers are wrongly given in the index, which also unfortunately omits a few of the authors mentioned in footnotes.

As an example of the care which the author has taken to make the book fully up-to-date, it may be mentioned that recent volcanic events discussed in some detail include, besides the Vesuvius eruption of March, 1944, already referred to, the activity at Rabaul, New Britain, in 1937, and that in Mexico in 1943–44 which gave rise to the 1500-foot cone Parícutin. Both these new volcanoes are illustrated by photographs.

SOME IGNEOUS ROCKS FROM THE NEW PLYMOUTH AREA, BY C. OSBORNE HUTTON

REVIEW BY BURTON WALLACE COLLINS[1]
Auckland, New Zealand

"Some Igneous Rocks from the New Plymouth Area," by C. Osborne Hutton, petrologist, New Zealand Geological Survey. *Trans. Roy. Soc. New Zealand*, Vol. 74, Pt. 2 (September, 1944), pp. 125–52; 2 pls., 4 figs.

According to the official estimate of the New Zealand Department of Mines, the total production of petroleum from wells in New Zealand, to December 31, 1943, amounted to 3,337,577 (British Imperial) gallons. Probably about nine-tenths of this was produced from a small area near the town of New Plymouth, on the west coast of the North Island. Over the past 8 years production from this field has averaged slightly more than 100,000 gallons annually, but appears to be declining.

The bulk of the oil at New Plymouth has come from strata of probably Late Miocene age at depths between 2,100 and 2,300 feet below sea-level, but there are also oil-bearing zones at about 1,000 feet and 3,000 feet, while "shows" of oil and gas were obtained nearly to the greatest depth reached prior to 1942 (5,726 feet). Drilling began as early as 1865

[2] C. A. Cotton, "Oahu Valley Sculpture: A Composite Review," *Geol. Mag.*, Vol. 80, No. 6 (November-December, 1943), pp. 237–43; 5 figs.

[3] *Landscape as Developed by the Processes of Normal Erosion* (Cambridge, 1941); *Climatic Accidents in Landscape-Making* (Christchurch, 1942). Both reviewed in this *Bulletin* (July, 1943).

[1] P.O. Box 10, Auckland C1. Manuscript received, April 17, 1945.

with the Alpha or "Oil or London" well, which reached a total depth of 180 feet; but the most productive wells (if such a term may be used in this only semi-commercial field) were drilled between 1930 and 1934 to depths between 2,127 and 3,310 feet. Altogether about 30 holes have been put down in the immediate vicinity, all except three of which have now been abandoned.

The presence of oil in this locality is said to have been known to the Maoris (the indigenous Polynesian inhabitants of New Zealand) long before the arrival of Europeans.

> Strong escapes of oil take place from time to time on the foreshore at New Plymouth breakwater close to a mass of coarse-textured andesitic rock which in some way is considered to be connected with the seepage.[2]

It is entirely because of this seepage that the area has been drilled, as the structure of the sedimentary beds is masked by a cover of volcanic debris of varying thickness extending for several miles inland from New Plymouth. From evidence obtained where the beds crop out, however, it is known that the whole Taranaki district (extending both northeast and southeast of New Plymouth) is, in a broad sense, a great monocline with dips in general at low angles toward the south and west. This regular structure is diversified in places by major faults and by belts of irregular more or less gentle folding.

In order further to test the possibilities at New Plymouth, especially at greater depths than had been previously reached, the New Zealand Petroleum Company recently drilled two wells near the town. Both wells were dry and have been abandoned, but one (Devon No. 1, total depth 9,412 feet, one of the deepest wells in the southern hemisphere) yielded some interesting geological information which is the basis of a new theory of the structure of the district advanced by Hutton in the paper here reviewed.

The New Zealand Petroleum Company was incorporated in 1938, just after the passing of the Petroleum Act of 1937 which made conditions in New Zealand attractive for strong petroleum-prospecting organizations. After drilling eight major wells, of an aggregate depth of 52,105 feet, without encouraging results, the company has recently (December, 1944) ceased operations. Two of its wells, Devon No. 1 already mentioned, and Midhirst No. 1, total depth 10,925 feet (also in Taranaki, about 20 miles southeast of New Plymouth), were record achievements, being the deepest wells anywhere south of the equator. More than a hundred holes of a total footage of about 136,000 feet were drilled for structural information by the same company with smaller plants. The exploration campaign is reported to have cost nearly £1,000,000. The three share-holding companies were: Standard of California, Texas Investments, and Shale Oil Investigations, the last-named being an Australian and New Zealand group.

The Devon No. 1 bore, after penetrating 280 feet of tuffs, passed down through a thick series chiefly of fine sandstones and siltstones ranging in age from early Pliocene or latest Miocene to older Miocene, and at a depth of 9,388 feet encountered a porphyrite in which drilling was continued for a distance of 31 feet. Although little is known of the structure of this mass, Hutton considers it to be a sill rather than a dyke or flow. A re-examination of the mineralogy and petrology of the andesites, dacites, and hybrid rocks of Paritutu, Mataora Island, and Ngataierua Point (in the immediate vicinity of the oil seepage at New Plymouth, and about 1½ miles northwest of the Devon No. 1 bore) has convinced him that they are genetically connected with the prophyrite sill.

> It is the writer's contention that magma from the chamber now occupied by this porphyrite was injected upwards along a series of tension cracks or planes caused by a doming-up of the magma chamber [p. 147], thus developing a series of cone-sheets. Subsequent erosion has reduced these cone-sheets, the Sugarloaves [the pinnacle of Paritutu on the mainland and several neighbouring islands] being the remnants of the former continuous outcrops [p. 127]. A close study of the islands suggests

[2] J. Henderson, "Petroleum in New Zealand," *New Zealand Jour. Science and Technology*, Vol. 19, No. 7 (December, 1937), pp. 401–26.

the existence of at least two cone-sheets, although surface traces of additional ones may have been completely removed by erosion. If one allows a regular dip of 40°–50° for the cone-sheets a simple construction indicates the depth of the cone-sheet foci to be about 5,000 feet. At this point, therefore, a considerable upward extension of the magma chamber must be present for the upper surface of the porphyrite body was touched only at 9,388 feet in the Devon No. 1 bore, situated just two miles south-east of the centre of the cone-sheet structure [p. 130]. The outer sheet appears to have a thickness of approximately 600 feet to 700 feet, whereas the supposed inner one would not exceed 200 feet to 300 feet [p. 130].

Known oil seepages have been observed in a number of places close to the Sugarloaf Islands and in all cases these were located on the outer periphery of the elliptical zone in which the islands and Paritutu lie. To the writer's knowledge, oil seepages are unknown within this zone, and if the hypothesis . . . is correct, then seepages are not to be expected here [p. 127].

Earlier opinion[3] was that the igneous rocks of this locality were lavas, but, as pointed out by Hutton in the present paper, an earlier well, drilled about 10 chains east of Paritutu, after passing through a thin, superficial cover of tuff and agglomerate,

went to a depth of nearly 3,000 feet in fairly homogeneous mudstones, without encountering any massive igneous material. If Paritutu were made up of dacite flows, their eastward extension would certainly be expected.

Later[4] the igneous rocks were

interpreted either as a vast plug or series of plugs intrusive into [the Tertiary strata] or as a volcanic neck round which they were deposited. Gravimetric observations seem to indicate that the volcanic islands of the Sugar-loaves together with Paritutu, a pike on the shore 505 feet high, belong to a single large body of rock which in depth greatly decreases in size; in fact, that the outcrops of volcanic rock are the ruins of a volcano of which the vent pierces the Pliocene strata.

Hutton's cone-sheet theory seems to satisfy all the evidence at present available, and although, according to the reviewer's understanding, cone-sheets usually pierce igneous material on the sites of ancient volcanoes, there does not seem to be any inherent improbability in his interpretation that at New Plymouth sediments have been penetrated in this way. The structural evidence seems rather meager, however, and observations on the joint systems and crystal orientation (if any) of the rocks of the unexamined islands forming the remainder of the supposed cone-sheet outcrops would be desirable.

Whatever the detailed structure of the igneous rocks at New Plymouth, however, the following remarks by Henderson[5] still appear to be well founded.

The petroleum seepages are on the up-slope side of the contact of the igneous rock with the strata of the Taranaki sedimentary monocline and may be escaping from a trap structure on the seaward side of the Sugar-loaves. The overflow from the oil-pool in the hypothetical trap structure fed, and perhaps is still feeding, the oil-sand the wells at New Plymouth tap. On this interpretation a well on the shore west of Paritutu drilled through its projecting base of igneous rock into the sediments below might give good results.

The proposed well yet remains to be drilled. Until it is, the New Plymouth area can not be said to be fully tested.

[3] E. de C. Clarke, "The Geology of the New Plymouth Subdivision, Taranaki Division," *New Zealand Geol. Survey Bull. 14* (1912). 58 pp., 2 maps.

[4] J. Henderson, *op. cit.*

[5] *Op. cit.*

RECENT PUBLICATIONS

APPALACHIAN REGION

"Map of the Berea Sand of Southeastern Ohio, Northern West Virginia, and Southwestern Pennsylvania," by James F. Pepper, David F. Demarest, Richard D. Holt, Wallace de Witt, Jr., and Charles W. Merrels, 2d. *U. S. Geol. Survey Prelim. Map 29* (May, 1945). Map, 43×64 inches. Scale, 1 inch equals 3 miles. Shows oil and gas possibilities. Smaller maps, a cross section, a diagram, and brief text printed on the single sheet. Obtainable from Director of the Geological Survey, Washington 24, D.C. Price, $0.60.

ARIZONA

"Late Paleozoic Stratigraphy and Oil and Gas Possibilities of Central and Northeastern Arizona," by J. W. Huddle and E. Dobrovolny. *U. S. Geol. Survey Prelim. Chart 10*, Oil and Gas Inves. Ser. (May, 1943). 27 graphic sections of formations at surface and in wells, and a key map, on one sheet, 44×50 inches. Text printed on the sheet. Obtainable from Director of the Geological Survey, Washington 25, D. C.; Room 234, Federal Building, Tulsa, Oklahoma; Room 314, Boston Building, Denver, Colorado; Room 533, U. S. Post Office and Courthouse Building, Los Angeles, California. Price, $0.40.

AUSTRALIA

*"The Hutton Creek Bore, Queensland," by Irene Crespin. *Australia Dept. Supply and Shipping, Mineral Resources Survey Rept. 1945/14* (*Plan 1187*) (Canberra, February, 1945). 3 mim. pp. and diagrammatic log.

*"The Arcadia Bore, Queensland," by Irene Crespin. *Ibid., Rept. 1945/15* (*Plan 1188*). 7 mim. pp. and diagrammatic log.

*"Preliminary Notes on a Microfauna from the Lower Cretaceous Deposits in the Great Artesian Basin," by Irene Crespin. *Ibid., Rept. 1945/16* (*Plan 1189*). 5 pp. and sketch map.

BRAZIL

*"Brazil's Search for Oil," by L. J. Logan. *Oil Weekly*, Vol. 118, No. 2 (Houston, June 11, 1945), pp. 34–36; 2 maps.

CALIFORNIA

"Geology of Oil-Impregnated Diatomaceous Rock near Casmalia, Santa Barbara County, California," by M. Dean Williams and Clifford N. Holmes. *U. S. Geol. Survey Prelim. Map 34*, Oil and Gas Inves. Ser. (May, 1945). Single sheet, 24×32 inches. Topographic and geologic map on scale of 1 inch equals 300 feet. Cross section and text included. Available from Director of the Geological Survey, Washington 25, D. C., and 533 U. S. Post Office and Courthouse Building, Los Angeles, California. Price, $0.40.

*"Rio Vista Gas Field," by R. G. Frame. *California Oil Fields*, Vol. 30, No. 1, January-June, 1944 (San Francisco, June, 1945), pp. 5–14; 3 pls.

*"Report and Recommendations to the California State Reconstruction and Reemployment Commission," by the State Aerial Mapping Project Committee (March, 1945), Olaf P. Jenkins, chairman. 137 multigraphed pp., 13 pls. "The use of modern aerial mapping methods and the development of a sound and complete basic mapping program for California is fundamental to the effective and full development of the State's resources in the postwar years."—From the Foreword. State Reconstruction and Reemployment Commission, 631 J Street, Sacramento 14, California.

ENGLAND

*"The Stratigraphy, Structure and Mineralization of the Greenhow Mining Area, Yorkshire," by Kingsley Charles Dunham and Cyril James Stubblefield. *Quar. Jour. Geol. Soc. London*, Vol. 100, Nos. 399–400, Pts. 3–4 (Longmans, Green and Company, Ltd., 43 Albert Drive, S.W. 19, London, March, 1945), pp. 209–68; 1 pl. (area geology in colors), 1 pl. (fossils), 6 figs. (geologic sections and maps). Contains descriptions of Carboniferous Limestone series and Millstone Grit series.

*"The Structure and Ore Deposits of the Carboniferous Limestone of the Eyam District, Derbyshire," by Jack Shirley and Ernest Lockwood Horsfield. *Ibid.*, pp. 289–308; 1 pl. (geologic map), 3 figs. (geologic sections and map). Ordovician and Silurian rocks.

*"On Some New Permian Fossils from the Magnesian Limestone near Sunderland," by Charles Taylor Trechmann. *Ibid.*, pp. 333–54; 1 pl. (fossils), 4 text figs.

FRANCE

*"New Field in France Being Developed," by Weldon Hill. *Oil Weekly*, Vol. 117, No. 13 (Houston, May 28, 1945), pp. 46–48; 2 sketch maps, 3 photographs.

GENERAL

*"Water Permeability of Reservoir Sands," by Norris Johnston. *Petrol. Tech.*, Vol. 8, No. 3 (New York, May, 1945). 12 pp., 7 tables. *A.I.M.E. Tech. Pub. 1871.*

*"Radioactivity Well Logging. Pt. 1. Gamma Ray Measurements," by Robert E. Fearon. *Oil Weekly*, Vol. 118, No. 1 (June 4, 1945), pp. 33–41; 7 figs. Contains a bibliography of 66 references.

*"Tentative Genetic, and Morphologic Classification of Oil and Gas Fields," by Sylvain J. Pirson. *Mineral Industries*, Vol. 14, No. 8 (Pennsylvania State College, May, 1945), pp. 1–4.

*"Problems and Research in Water Flooding," by S. T. Yuster. *Jour. Inst. Petroleum*, Vol. 31, No. 257 (London, May, 1945), pp. 121–28.

*"Genetic and Morphologic Classification of Reservoirs," by Sylvain J. Pirson. *Oil Weekly*, Vol. 118, No. 2 (Houston, June 18, 1945), pp. 54–59; 3 graphic charts.

"Bibliography on the Petroleum Industry," by E. DeGolyer and Harold Vance. *Texas Eng. Exper. Sta. Bull. 83* (College Station, Texas). Approx. 800 pp., 20,000 items, 900 subject headings. Price: $2.00, paper; $3.00, clothbound.

*"The Nation's Reserves of Natural Gas," by E. DeGolyer. *Oil and Gas Jour.*, Vol. 44, No. 4 (Tulsa, June 23, 1945), pp. 76–78. Abridged summary of paper delivered before the Interstate Oil Compact Commission, Oklahoma City, June, 1945.

GULF COASTAL PLAIN

The Important Oil and Gas Fields of South Arkansas, North Louisiana, Mississippi, and Alabama. Prepared and published by the Shreveport Geological Society (1945). Approx. 300 pp., illus.

This volume will present the important geological, engineering, and statistical data of fifty-five fields, as assembled and interpreted by members of the Society and other geologists in Shreveport and its area.

Each pool is presented individually and is accompanied by a map. Where possible, a structural interpretation is shown. The section is illustrated either by cross section or columnar type section. The history of each field and state of development are outlined, and production statistics are given, together with such other pertinent data as market facilities and processing plants. Also included in the volume are two regional cross sections: one from north to south through Arkansas and Louisiana, the other from west to east across northern Louisiana and Mississippi.

Although prepared by and for geologists, the book is also designed to be of value to engineers, oil-company executives, investors, producers, and all others engaged in or concerned with the oil and gas production of the eastern part of the Upper Gulf Coast.

Date of publication, August 1. Pre-publication price, $10; after August 1, $12.50. Order from Shreveport Geological Society, L. H. Meltzer, secretary-treasurer, Box 750, Shreveport, Louisiana.

KANSAS

*"The Correlation of Rocks of Simpson Age in North-Central Kansas with the St. Peter Sandstone and Associated Rocks in Northwestern Missouri," by Constance Leatherock. *Kansas Geol. Survey Bull. 60*, Pt. 1 (Lawrence, June 1, 1945). 16 pp., 1 pl., 2 figs.

LOUISIANA

*"An Engineering Study of the Lafitte Oil Field," by Harold Vance. *Petrol. Tech.*, Vol. 8, No. 3 (New York, May, 1945). 15 pp., 13 figs. *A.I.M.E. Tech. Pub. 1869.*

OKLAHOMA

"Secondary-Recovery Possibilities of the Nowata-Claggett Field, Nowata County, Oklahoma." *U. S. Geol. Survey.* An informal report available from the Oil and Gas Supervisor, U. S. Geological Survey, Federal Building, Tulsa, Oklahoma.

"Analyses of Crude Oils from Some Fields of Oklahoma: III." *U. S. Bur. Mines Rept. of Investig. 3802* (Washington, D. C., June, 195).

UTAH AND WYOMING

"Geologic and Structure Contour Map of the Clay Basin Gas Field and Vicinity, Daggett County, Utah, and Sweetwater County, Wyoming," by C. E. Dobbin and R. P. Davison. *U. S. Geol. Survey* (May, 1945). Sheet, 15×26 inches. Scale, 2 inches equals 1 mile. Available from the Director of the Geological Survey, Washington 25, D. C.; Federal Building, Casper, Wyoming; and Room 314, Boston Building, Denver, Colorado. Price, $0.15.

VIRGINIA-KENTUCKY

*"Middle Ordovician Limestones from Lee County, Virginia, to Central Kentucky," by George Garrett Huffman. *Jour. Geology*, Vol. 53, No. 3 (Chicago, May, 1945), pp. 145–74; 9 figs.

WASHINGTON

"Preliminary Geologic Map and Brief Description of the Coal Fields of King County, Washington," by W. C. Warren, H. Horbisrath, R. M. Grivetti, and S. P. Brown. Single sheet, 44×64 inches. Scale, 2 inches equals 1 mile. Contains 3 cross sections, 31 graphic sections, table, and text. Obtainable from Director of the Geological Survey, Washington 25, D. C. Price, $0.50.

WYOMING

"Geology of the Washakie Basin, Sweetwater and Carbon Counties, Wyoming, and Moffat County, Colorado," by Wilmot H. Bradley. *U. S. Geol. Survey Prelim. Map 32*, Oil and Gas Inves. Ser. (May, 1945). Sheet, 28×52 inches. Scale, 1 inch equals 3 miles. Distribution and structure of surface rocks. Explanatory text and graphic section printed on the sheet. Obtainable from Director of the Geological Survey, Washington 25, D. C.; Federal Building, Casper, Wyoming; Room 314 Boston Building, 823 Seventeenth Street, Denver, Colorado. Price, $0.40.

"Geology of Northwest End of the Wind River Mountains, Sublette County, Wyoming," by Gerald M. Richmond. *U. S. Geol. Survey Prelim. Map 31*, Oil and Gas Inves. Ser. (June, 1945). Sheet, 32×50 inches. Scale, 1 inch equals 1 mile. On same sheet are stratigraphic section, sketch map, and brief text.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 7 (JULY, 1945), PP. 1054-1058

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS PREPARATION OF MANUSCRIPTS[1]

AUTHOR[2]
City and State

ABSTRACT

Helpful suggestions to authors issued by other scientific societies are here adapted to the requirements of the Association *Bulletin*. The arrangement is that of a correctly prepared manuscript. These abstracts should be prepared for all major papers submitted for publication and for all titles to be presented on Association programs. Abstracts should state all major and minor topics in which new facts are involved and should mention all conclusions reached. They must be brief.

Introduction

It is taken for granted that authors of papers in the *Bulletin* desire to give all possible aid in achieving the highest possible publication standards and in lightening editorial burdens. Consideration of the suggestions presented here, and conformation to the arrangement and style of current papers in the *Bulletin* will assist very materially the work of the editorial staff. This outline is being published in the *Bulletin* in order that it may be readily available to all members. It is hoped that the instructions it contains will be helpful to those who contemplate the preparation of manuscripts.

Title of Paper

A title should be brief, and should not attempt to summarize the paper. The first word in a title should be an important one, and, if possible, one helpful in indexing the article. It is seldom desirable to begin a title with indefinite words such as "A," "The," "Notes," or with phrases such as "On the," "Some considerations," and similar expressions.

Writing

In scientific writing, clearness and conciseness are of prime importance. Careful examination to see that what one desires to say is said without ambiguity or circumlocution, that construction is correct, and that sentences are neither too long and involved nor too short and choppy, will improve a paper greatly. Correction and criticism by a friend or colleague may be very helpful.

Usage of the *Bulletin* should be followed in preparing manuscript for publication in it. Generally, extreme abbreviations and the like are not good form: write 1,990 feet, not 1990′; well No. 3, not #3; Sec. 12, T. 6 S., R. 5 E., not 12-6-5 or 12-6S-5E. It is considered desirable to avoid use of the first person.

Typewritten Form

All contributions should be typewritten and preferably should be direct imprints rather than carbon copies. The task of marking a single-spaced manuscript for the printer is one of the most vexing to confront an editor. All manuscripts submitted for publicaton should, therefore, be double-spaced, or better still, triple-spaced; even tables and footnotes should not be single-spaced.

[1] Read before the Association at the _____ meeting, _____ (date).
Manuscript received, _____ [date]. [This safeguards the author's priority.]
Published by permission of _____ [name of official or company].

[2] [Business or professional connection. Acknowledgment of assistance and thanks for criticism may be placed in this footnote.]

Headings

Outline.—Though a table of contents is not printed at the beginning of a published article, it is advisable to prepare carefully an outline to follow in writing the paper. The outline will make for desirable condensation and logical arrangement of the material; and its parts will constitute the headings of the topics in the text.

Rank.—Headings have first, second, third, or fourth rank, dependent on their relative importance. They have corresponding positions in the manuscript and certain styles and sizes of type are used by the printer for each rank of heading. Attention by the author to the rank of headings which are introduced will aid him in logical arrangement and presentation of his paper and will assist editor, printer, and reader.

Means of designation.—A first heading should be written in capitals midway across the page. A heading of second rank may also be placed centrally as illustrated by the caption "Headings" at the beginning of this section; if so placed it is set by the printer in small capitals. If no headings of lower rank are used, it is common practice to place subordinate headings at the side as shown at the beginning of this paragraph.

Footnotes and References

Footnotes and references should be inserted at any place in the text where needed, continuous reference numbers being used, and the notation being made between two lines. References should be abbreviated and should follow the form used in current numbers of the *Bulletin*. The following[3] are typical, correctly arranged references.

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[3] Frederic H. Lahee, "Exploratory Drilling in 1944," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 6 (June, 1945), pp. 629–45.

M. Grace Wilmarth, "Lexicon of Geologic Names of the United States," *U. S. Geol. Survey Bull. 896*, Pt. 2 (1038), p. 1455.

An exception to this arrangement is permissible if a long reference list in bibliographic form is printed at the end of the paper, in which case numbers are inserted thus (1) throughout the text, no other notations being used.

Illustrations

Importance.—Good illustrations are the heart and soul of many papers. No reasonable effort should be spared in making them effective. Fortunately, practically every geologist can, with care and patience, prepare entirely satisfactory drawings and other types of illustrations.

Title and location.—Each illustration should bear the author's name, the title, and amount of reduction desired, due regard being given to the size of the *Bulletin* page. The position of each illustration in the manuscript should be indicated by writing the title across the page between two ruled lines, thus:

Fig. 1.—[Title of illustration; cut line which will be set in type below the cut.]

Legibility after reduction.—Because photographic reduction of about half size minimizes undesirable irregularities in drafting, illustrations intended for publication should, in general, be approximately twice the size in linear dimensions of the figure as it will appear in the *Bulletin*. Most important is forethought by the author concerning size and legibility after reduction. He may frequently find it helpful to examine his illustrations through the ground glass of a reducing camera. No printing should appear on the original drawing which after reduction will be less than 1/50 inch in height.

Preparations of drawings.—The *Bulletin* page available for illustrations is 6 inches wide and 9 inches long. All illustrations should be so prepared that they may be reduced to dimensions not greater than these and yet be perfectly legible. Illustrations so large or of such shape that it is necessary to fold them into the *Bulletin* are costly. Authors should, where possible, avoid them. Drawings should be in black, preferably India ink on tracing cloth. Colored illustrations can be used only under the most exceptional circumstances. Black-line prints, if clear, make satisfactory "copy." Photostat copies of drawings are generally "muddy" or blurred and are not desirable for reproduction. Where cross-section paper is used, it is important to take into account the effect of reduction on the appearance of a graph; a fine-ruled paper is undesirable, and even a coarse-ruled paper may give an unsatisfactory result on reduction. It is perhaps best to prepare a graph on tracing cloth, ruling in only the lines desired in the published figure. Orange, red, blue, and green lines photograph black. A graphic, bar scale, for miles or feet, should be drafted on maps. Failure of authors to consider some of these matters has caused expensive re-drafting.

Photographs.—Photographs should be very clear, show moderate contrast, and should be finished with a glossy surface. It should, perhaps, be frankly stated that the half-tone process used by the *Bulletin* to reproduce photographs is not entirely satisfactory where detail is required as, for example, in figuring new and little known species of fossils. The process, however, has certain advantages for the reproduction of the usual type of photograph published in the *Bulletin*.

Summary.—Planning of each illustration with the size and shape of the page in the *Bulletin* in view will improve greatly the appearance and value of the published figure.

Publication

Papers accepted for publication in the *Bulletin*, or for presentation at Association meetings, are the property of the Association. Members desiring prior publication of such papers in trade journals, or elsewhere than in the *Bulletin*, should submit to the business manager complete duplicate copies of the paper and the illustrations, together with the name of the periodical in which publication is desired. Papers printed in trade journals or elsewhere without having been submitted to the business manager are not eligible for publication in the *Bulletin*.

Conclusions

These simple suggestions are only a few of those which might, perhaps, be made, but it is hoped that they are sufficient to give prospective authors a general idea of the most desirable form for manuscript copy. Those who write for the pages of the *Bulletin* desire the best for their papers and for the publications as a whole. Careful attention to the principles presented here can go far toward achieving it. The editorial staff deeply appreciates the assistance, courtesy, and patience of its many contributors.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The Pittsburgh Geological Society, a regional group "to advance and disseminate geologic knowledge, and to provide a forum for geological problems," was recently organized with the following as officers: president, GEORGE C. GROW, JR., Peoples Natural Gas Company; vice-president, RAYMOND E. BIRCH, Harbison-Walker Refractories Company; secretary, W. B. ROBINSON, Gulf Research and Development Company, Box 2038, Pittsburgh 30; treasurer, SHAILER S. PHILBRICK, United States Engineers. These officers, together with the following, comprise the Council: ROBERT E. BAYLES, HUGH R. BRANKSTONE, C. H. FELDMILLER, RICHARD M. FOOSE, JOHN T. GALEY, DAVID K. KIRK, and J. H. C. MARTENS. Speakers at the first six meetings and their subjects follow: Major RAYMOND C. MOORE, State Geologist of Kansas, now on leave in the Army, "Geology and Geomachy"; KIRK BRYAN, Harvard University, "The Geological Antiquity of Man in America"; CAREY CRONEIS, president, Beloit College, "Science and the Future"; PHILIP S. SMITH, chief Alaskan geologist of U.S.G.S., "Alaska's Potential Oil Resources"; W. C. KRUMBEIN, senior geologist, Beach Erosion Board, "Sedimentation and Its Relation to Oil Finding"; and WALTER H. BUCHER, professor of geology, Columbia University, "The Deformation of the Earth's Crust."

J. A. MULL, JR., geologist for the Superior Oil Company of California at Wichita, Kansas, went to Bermuda recently, for exploratory work.

EUGENE HOLMAN, president of the Standard Oil Company (New Jersey), New York City, delivered the commencement address at the University of Oklahoma, at Norman, May 28.

W. H. TWENHOFEL, of the University of Wisconsin, Madison, is engaged in field work this summer for the Newfoundland Geological Survey at St. John's, Newfoundland.

PARKER D. TRASK has completed his assignment with the Office of Scientific Research and Development on which he has been engaged for the past year.

HENRY SCHWEER, independent operator of Oklahoma City, and GEORGE P. HARDISON, geologist with the Shell Oil Company, Inc., Wichita Falls, Texas, have formed a partnership to be known as Schweer and Hardison, for consulting work. The firm is located in Oklahoma City, Oklahoma.

JOSEPH S. HOLLISTER, formerly with the United Geophysical Company, is engaged in consulting geology at Gaviota, California.

JAMES H. MCCOURT may be addressed in care of the Union Oil Company of California, Cut Bank, Montana, since the purchase of the Glacier Production Company by the Union Oil Company.

ARTHUR LELAND SNOW is with the Petty Geophysical Engineering Company, c/o Richmond Exploration Company, Apartado 93, Maracaibo, Venezuela.

J. BROOKES KNIGHT has resigned his position as lecturer and curator in the geology department at Princeton University to accept an appointment as research associate in paleontology in the Smithsonian Institution. His new address is United States National Museum, Washington 25, D. C.

The annual picnic of the Pacific Section of the Association, at Los Angeles, California, was held on May 11, with an attendance of 164. The annual fall meeting of the Section will be held at the Ambassador Hotel on November 8 and 9.

The annual picnic of the South Texas Section (San Antonio) of the Association was held at Starke Park, Seguin, Texas, June 2. The guests of the Section were 100 wounded veterans from Brooke General Hospital, San Antonio.

At the 112th commencement of Denison University, CAREY CRONEIS, formerly professor of geology at the University of Chicago, and now president of Beloit College, Wisconsin, was awarded the honorary degree of Doctor of Science "in recognition of his achievements as a brilliant discoverer and interpreter of ancient forms of life, and as a thorough and patient teacher of earth science."

ROBERT T. WHITE has been appointed chief geologist of the Barnsdall Oil Company, succeeding E. W. GALLIHER, recently deceased, at Los Angeles, California.

MICHAEL W. BECKMAN, formerly with the Continental Oil Company at Lafayette, Louisiana, is with the Skelly Oil Company of Shreveport, Louisiana.

FRANK R. CLARK, vice-president and division geologist for the Ohio Oil Company at Tulsa, Oklahoma, has been assigned to special problems involving geology and related matters. He will act in an advisory capacity to the geological, land, and executive departments. RALPH A. KOENIG has been transferred from Findlay, Ohio, to Tulsa, where he is now division geologist for the company. R. W. MCCANNE has been appointed division geologist at Casper, Wyoming, succeeding C. J. HARES, who is now in charge of geologic research for foreign fields and foreign prospective oil and gas provinces.

New officers for the Oklahoma City Geological Society are: president, RALPH L. FILLMORE, Anderson-Prichard Oil Company; vice-president, ROY D. MCANINCH, Stanolind Oil and Gas Company; secretary-treasurer, CARL A. MOORE, Carter Oil Company. A technical program meeting is held each month, subject to call by program committee, at Oklahoma City University, 24th Street and Blackwelder. Luncheon meetings are held every second Thursday at 12 noon, at the Skirvin Hotel. Visiting geologists are welcome at all meetings.

I. K. NICHOLS has resigned his position with The Texas Company in New Orleans, and has become district gellogist of South Louisiana with the Phillips Petroleum Company at Houston, Texas. His address is 524 Esperson Building.

GEORGE S. BUCHANAN, formerly president of the Yegua Corporation, Houston, has been appointed manager of the Gulf Coast division of the Sohio Petroleum Company, with headquarters at 2303 Neils Esperson Building, Houston, Texas.

GEORGE H. HARRINGTON is president of the Yegua Corporation, Houston, succeeding GEORGE S. BUCHANAN.

MAURICE R. TEIS has resigned his position as geologist with the Ohio Oil Company and has opened a consulting office as petroleum geologist in the Atlas Life Building at Tulsa.

CONRAD O. HAGE, has left the Geological Survey, Victoria Museum, Ottawa, Ontario, to join the Shell Oil Company of Canada, Bank of Toronto Building, Calgary, Alberta.

VIRGIL WINKLER is in the geological laboratory of the Creole Petroleum Corporation, Apartado 889, Caracas, Venezuela.

A. F. BECK has resigned from the Cities Service Oil Company. He may be addressed c/o Imperial Oil Company, 56 Church Street, Toronto, Ontario, Canada.

ABDUL KHALIQ MEHTA may be addressed at 197 Park Street, Calcutta, India.

JOHN L. PORTER, formerly with the Richfield Oil Corporation, Long Beach, California, has joined the Signal Oil Company.

J. B. UMPLEBY, independent and consultant, has moved from Seattle, Washington, to the Continental Building, Dallas, Texas.

V. DALE MARTIN is with the Foote Mineral Company, 1609 Summer Street, Philadelphia, Pennsylvania.

GEORGE A. SEVERSON, of The Texas Company, New York City, has changed his address to Apartado 267, Caracas, Venezuela.

CARL H. BEAL, consulting geologist, Los Angeles, California, addressed the Pacific Section of the Association, at the University Club, May 25. His subject was "A Reconnaissance of the Geology and Oil Possibilities of Baja California."

PHIL H. BOHART, assistant to the vice-president of the Gulf Oil Corporation, Tulsa, Oklahoma, has been appointed director of production for the Petroleum Administration for War, succeeding J. R. MCWILLIAMS, who returns to Tulsa as vice-president of the Carter Oil Company, in charge of production.

J. L. MCMANAMY, formerly staff geologist for 10 years with the Missouri State Geological Survey at Rolla, Missouri, has resigned his position there and is now associated with C. E. BREHM, consulting geologist, Mt. Vernon, Illinois, in the firm of Brehm and McManamy, consulting geologists. They also maintain an office in the Henry Building, Jackson, Mississippi.

Colonel BYRON RIFE has been awarded the Legion of Merit for outstanding services. At present he is in command of two of the Nation's largest munitions facilities, the Kankakee Ordnance Works (TNT) and the Elwood Ordnance Plant (loading of large-calibre shell and combs).

HEINRICH RIES, professor emeritus of geology at Cornell University, was given the honorary doctor of science degree at Alfred University's recent commencement exercises, "In recognition of a lifetime and devoted service in writing, teaching and organization and research in the twin fields of ceramics and geology." Ries joined the Cornell faculty in 1898, was made a professor in 1906, and head of the department of geology in 1914, filling that position until 1937. He retired in 1939. His retirement, however, consists of a voluntary daily schedule of research in McGraw Hall. During his career he has written more than 200 publications, including textbooks and reference books.

W. C. KRUMBEIN, who is on leave from the University of Chicago, has completed his war assignment in Washington, and has resigned as senior geologist of the Beach Erosion Board, War Department, to accept the position of research sedimentologist at the Gulf Research and Development Company, P.O. Drawer 2038, Pittsburgh 30, Pennsylvania.

E. DEGOLYER, of DeGolyer and MacNaughton, consultants, Dallas, Texas, has been elected a director of the Empire Trust Company of New York.

Major RAYMOND C. MOORE has been released from the Army after several years in service at Washington, D. C. He is spending several weeks with J. BROOKES KNIGHT and G. ARTHUR COOPER, of the United States National Museum, in the Glass Mountains, collecting fossils and studying Permian facies. After a brief time in his office as State geologist and director of the University of Kansas State Geological Survey, he plans to spend several months in petroleum geology research on an assignment for the United

States Geological Survey in Texas. His home address is 1605 Tennessee Street, Lawrence, Kansas.

A. NELSON SAYRE has returned to his duties in the United States Geological Survey, Washington, D. C., after having been loaned to the Army to act as a scientific adviser in the Southwest Pacific Area. His special work was in locating ground-water supplies, but he worked also on quarries and dock sites.

ROBERT STEEL, formerly with the Cities Service Oil Company at Midland, Texas, has been discharged from the Army, and has opened an office as consulting geologist at Oklahoma City, Oklahoma.

W. ARMSTRONG PRICE, consulting geologist, 908 Medical-Professional Building, Corpus Christi, Texas, talked on "Forms and Types of Scientific Writing" at the second annual Southwest Writers' Conference in Corpus Christi, June 5–7.

ALBERT I. GREGERSEN, of Los Angeles, California, who has been with the Petroleum Administration for War during the past 2 years, has been employed by the Danish American Prospecting Company to take charge of its program of exploration in Denmark.

JOSEPH JENSEN, of the Tide Water Associated Oil Company, has been elected chairman and CARLTON BEAL, of the Richfield Oil Corporation has been elected secretary of the Conservation Committee of California Oil Producers, Los Angeles.

EARL B. NOBLE, manager of exploration for the Union Oil Company, Los Angeles, California, was in Paraguay in June, reviewing company work on its concession in the Chaco area.

DOYLE MICHAEL BURKE has received a medical discharge from army service and is with The Texas Company geological department at Shawnee, Oklahoma.

HERBERT MOORE HOUGHTON has left the Tide Water Associated Oil Company at Houston, Texas, and is now with the United States Engineers at Santa Fe, New Mexico.

EUGENE B. WAGGONER, recently with the Superior Oil Company, is with the United States Bureau of Reclamation at Denver, Colorado.

CLINTON ENGSTRAND, formerly with the Shell Oil Company, Inc., at Saginaw, Michigan, has opened a consulting office at 428 Ritz Building, Tulsa, Oklahoma.

PAUL WEAVER, chief geophysicist with the Gulf Oil Corporation, at Houston, Texas, discussed "The Future of the Geologist in the Petroleum Industry" at the last regular meeting of the Houston Geological Society, June 7, prior to the summer recess.

MORELAND T. HARTWELL, recently with the Texas Gulf Producing Company, is now situated in Midland, Texas, engaged in consulting geology.

EDUARDO PFLUCKER has left Austin, Texas. He may be addressed at Ave. Benavides 498, Miraflores, Lima, Peru.

G. D. GIBSON is with the British-American Oil Producing Company, Tulsa, Oklahoma.

Captain E. W. K. ANDRAU has returned to civil life from his overseas duty as liaison officer in the Air Force, having been attached to the Dutch Air Force in the Netherland East Indies. He has again opened his offices, and may be addressed: Box 2408, Houston, Texas.

Captain PAUL N. DUDLEY, formerly with the Richfield Oil Corporation, is in the Marine Corps.

HENRY F. WISE, of the United Geophysical Company, may be addressed in care of the company, Apartado 1085, Caracas, Venezuela.

C. W. SHEPPARD, of the department of physics of the Massachusetts Institute of Technology, may be addressed at the School of Medicine, Vanderbilt University, Nashville, Tennessee.

C. F. DOBBIN, geologist with the United States Geological Survey, Denver, was elected, in June, to the presidency of the Colorado Engineering Council, the coordinating body for all engineering societies in the state.

Spencer Lens Company, Buffalo, New York, has recently become the Scientific Instrument Division of the American Optical Company. In announcing this change, Spencer Lens Company calls attention to a new booklet, *Three American Microscope Builders*, containing 77 pages, with illustrations. Charles A. Spencer built the first American microscope, at Canastota, New York, in 1837.

H. G. RAGGATT, director of the Mineral Resources Survey, Canberra, A. C. T., Australia, is in the United States and Canada for 6 months, visiting government, scientific, and industrial organizations. His address in this country is c/o Australian War Supplies Procurement, 1700 Massachusetts Avenue, NW., Washington, D. C.

ROBERT R. WHEELER, chief geologist for the Superior Oil Corporation of California at Oklahoma City, Oklahoma, has resigned to accept a similar position with the Eason Oil Company, Enid, Oklahoma.

WILLIAM B. KRAMER, geologist of the Conservation Branch of the United States Geological Survey, has been transferred from Denver, Colorado, to Tulsa, Oklahoma.

RAYMOND F. BAKER, chief geologist for The Texas Company, New York City, has been elected a director of the American Institute of Mining and Metallurgical Engineers, succeeding WALLACE E. PRATT, who recently retired.

DANA HOGAN, president and manager of the Hogan Petroleum Corporation, and JOHN F. DODGE, head of the petroleum engineering department, University of Southern California, Los Angeles, spoke recently before the Los Angeles Basin chapter of the American Petroleum Institute. Hogan's subject was "Functions of the Petroleum Industry War Council," and Dodge discussed "Recent Oil Developments in Venezuela."

Speakers at a recent meeting of the Pacific Section of the Association at Los Angeles, were GRANT W. CORBY and ROBERT M. KLEINPELL, who discussed their geological studies in the Netherlands East Indies and the Philippines.

WALTER M. SMALL, who has been for years with the Romano Americana at Bucharest, writes that the armistice of August 23, 1944, released him from *domicile forcat* of $2\frac{1}{2}$ years and he has resumed his advisory duties with his company. Associated with him is HANS HLAUSCHEK, chief geologist. Small's address is Calea Victoriei 126, Bucharest, Roumania.

Major JAMES A. WEBB, of the Lucey Petroleum Company, is with the Corps of Engineers. His home address is 1325 West Magnolia Avenue, San Antonio, Texas.

ION POPESCU VOITESTI, who retired as professor of geology at the University of Bucharest in 1941, died on October 4, 1944, as the result of injuries from a fall while hunting near his home in Voitesti, District of Gorj, Roumania. He was nearly 68 years of age.

CHARLES E. DECKER, research professor of paleontology at the University of Oklahoma, Norman, has been collecting Cambrian graptolites in eastern Tennessee and western Virginia. Dr. Decker's 77th birthday is September 27.

E. H. SELLARDS, director of the University of Texas Bureau of Economic Geology at Austin, having passed his 70th birthday, is now, in accordance with University regulations, free of administrative duties in the Bureau, effective Sepember 1. He has been with the Bureau since 1918 and has been its director since 1932. He has been professor of geology at the University since 1926.

Lieutenant Colonel JOHN T. LONSDALE, at present in the armed services, who has been professor of geology and head of the department at Iowa State College, Ames, Iowa, since 1935, has been appointed director of the Texas Bureau of Economic Geology, at Austin, succeeding E. H. SELLARDS, retired, effective September 1.

Major RUSSELL S. TARR, 2244 East Twenty-Fifth Place, Tulsa, Oklahoma, has returned from service in Washington, D. C.

CHESTER NARAMORE resigned as executive secretary of the Petroleum Division of the American Institute of Mining and Metallurgical Engineers, New York City, effective June 30. He became secretary in 1938.

FIELD CONFERENCE ON ELLENBURGER STRATA, LLANO REGION, TEXAS

A field conference on the Ellenburger group and related rocks of the Llano region of Texas was conducted from June 15 to 23 under the leadership of V. E. Barnes, of the Texas Bureau of Economic Geology, and P. E. Cloud, Jr., of the United States Geological Survey, assisted by L. E. Warren, of the Texas Bureau of Economic Geology. Ninety-one persons attended in a professional capacity. Twenty-seven producing oil companies were represented.

The introductory meeting on the night of June 14 was held in the auditorium of the Geology Building of the University of Texas. E. H. Sellards presided and T. S. Painter, president of The University of Texas, welcomed the group. H. D. Miser outlined the growth of the Ellenburger project and spoke of new projects to be developed. V. E. Barnes outlined the Ellenburger problem and P. E. Cloud, Jr., showed kodaslides. Following the oral program the group adjourned to the geology department's Museum to inspect sequentially arranged rock samples from representative sections, as well as stereoscopic pairs of aerial photographs, strip logs, maps, correlation charts, and Ellenburger building stones.

On the first part of the field conference representative sections were seen, together comprising a composite section of 1643 feet of Ellenburger strata, as well as the type locality of the Stribling formation of Devonian age.

Those completing the second part of the field conference saw a total of 13 measured sections of Ellenburger and associated rocks, which together comprise 6 complete composite sections. These sections were so distributed as to give the most detailed obtainable view of the Ellenburger rocks of the Llano region and most of them were marked at 5-foot intervals for sampling purposes. A number of additional points of interest were visited, including localities at which new Devonian rocks are exposed. Two of the composite sections studied extended from the pre-Cambrian well into or through the Ellenburger strata, and 3 others went at least well into strata of Cambrian age. The overlapping Mississippian, Pennsylvanian, and Cretaceous strata were briefly noted at favorable localities.

The 15 conferees who went as far west as Mason, Texas, were entertained on the night of June 21 at a barbecue given for them by Walker White and Homer Hughs at White's Mill Creek Ranch in Mason County.

Publications were issued to those who registered for the conference, as follows: "Stratigraphy of the Ellenburger Group in Central Texas—a Progress Report," by P. E. Cloud, Jr., V. E. Barnes, and Josiah Bridge; "The Devonian of Central Texas," by V. E. Barnes, P. E. Cloud, Jr., and L. E. Warren; and "Representative Sections of the Ellenburger Group in Central Texas," by V. E. Barnes and P. E. Cloud, Jr.

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Luncheons every Friday noon, Cosmopolitan Hotel. Evening dinner (6:15) and program (7:30) first Monday each month or by announcement, Cosmopolitan Hotel.

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Meetings will be announced.

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Secretary-Treasurer - - - Edward A. Huffman
J. M. Huber Corporation, 407 First National Bank Building

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

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The California Company, 1818 Canal Bldg.

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

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Sohio Petroleum Corporation, Atlas Building

Meets the first Monday of every month, September to May, inclusive, 7:30 P.M., Criminal Court Room, Caddo Parish Court House. Special meetings and dinner meetings by announcement.

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Magnolia Petroleum Co., Box 872
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Atlantic Refg. Co., Box 895
Treasurer - - - - - - - - P. F. Haberstick

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

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Cities Service Oil Co., Box 149, Mt. Pleasant
Business Manager - - - Harry J. Hardenberg
Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

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Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

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Secretary-Treasurer - - - - - Carl A. Moore
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1300 Apco Tower

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second Thursday, at 12:00 noon. Skirvin Hotel.

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Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

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Editor - - - - - - - Charles J. Deegan
Oil and Gas Journal, Box 1260

Meetings: First and third Mondays, each month, from October to May, inclusive at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Tuesday (October-May), Bradford Hotel.

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Secretary-Treasurer - - - - Elsie B. Chalupnik
Barnsdall Oil Company, 604 Driscoll Building

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Stanolind Oil and Gas Company, Box 660

Meetings: Regular meetings at 7:30 P.M., the second Monday, each month, City Hall.

Luncheons: Noon, fourth Monday, each month, Blackstone Hotel.

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Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

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Stanolind Oil and Gas Company
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Superior Oil Company, 807 Hamilton Building

Luncheons and evening programs will be announced.

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638 Milam Building

Secretary-Treasurer - - - - Marion J. Moore
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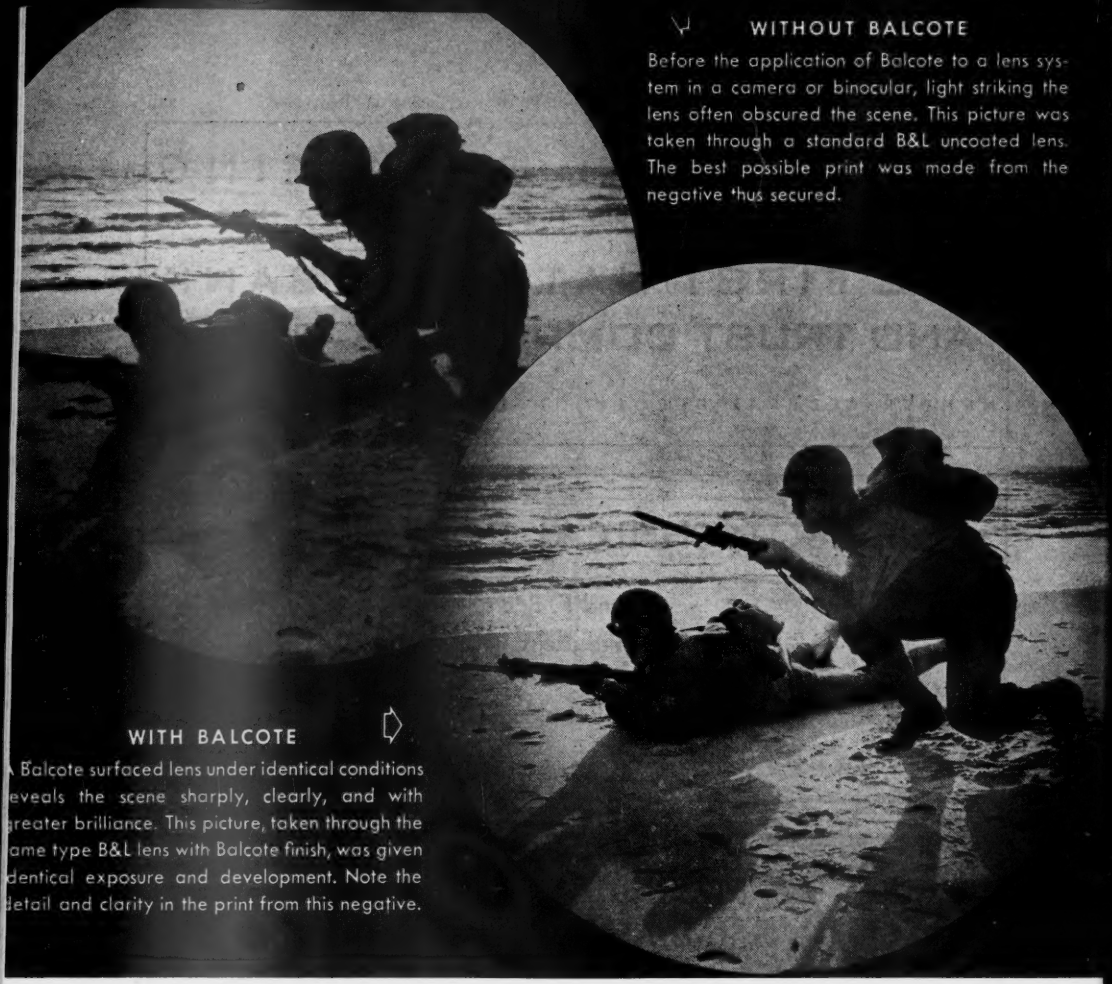

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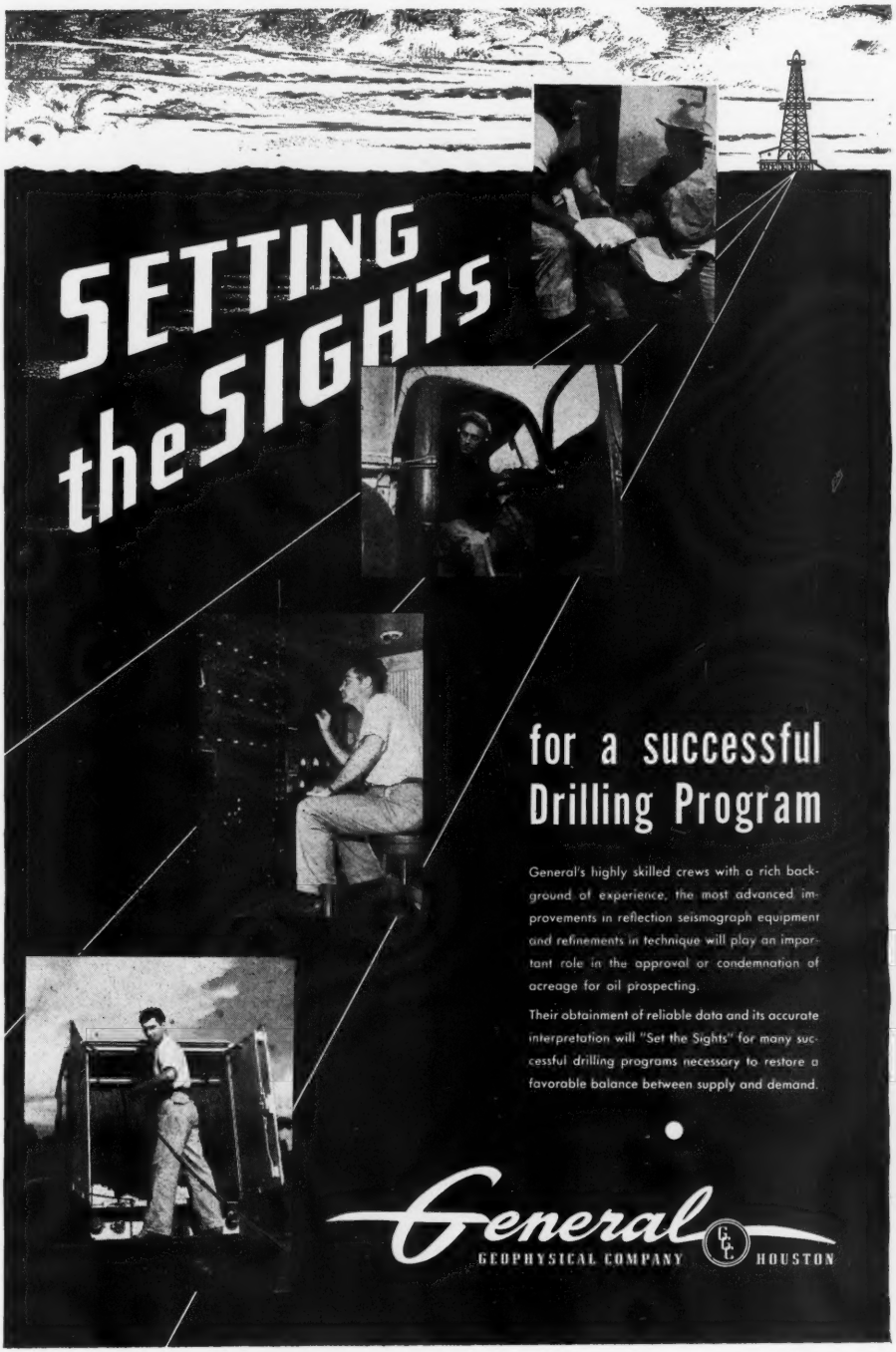
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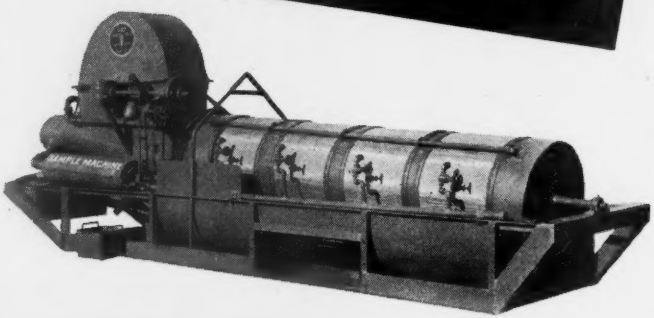

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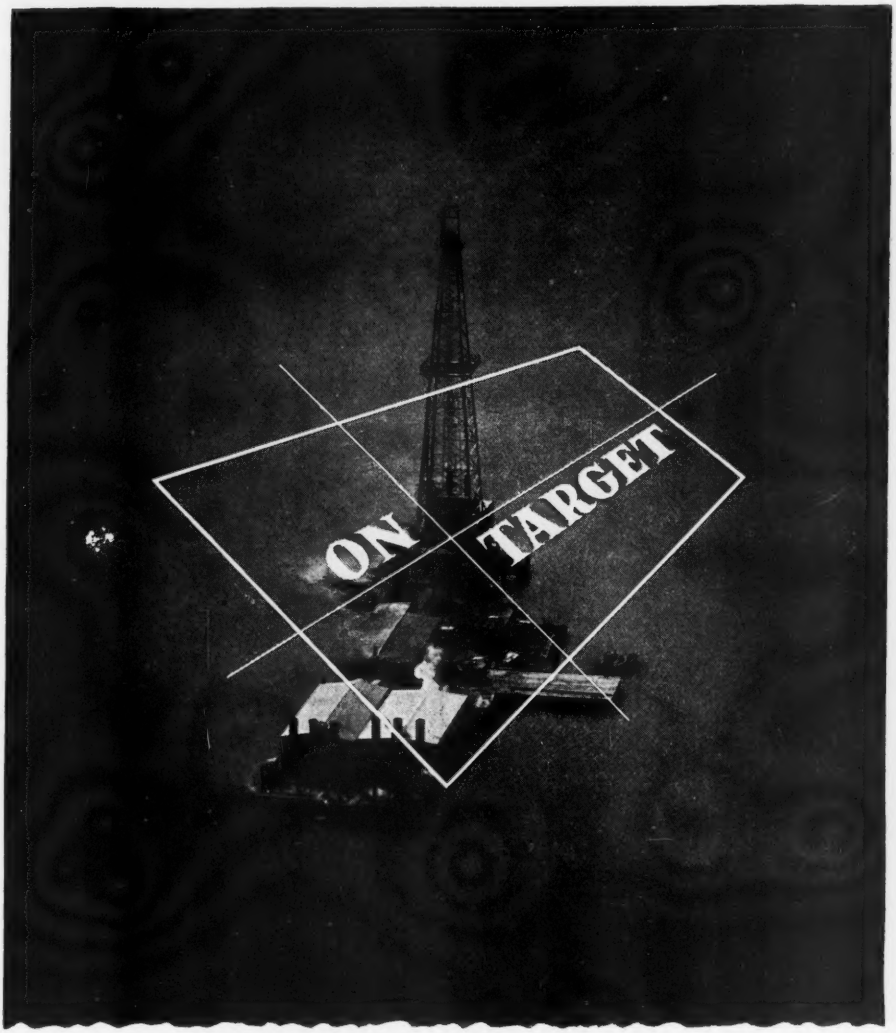

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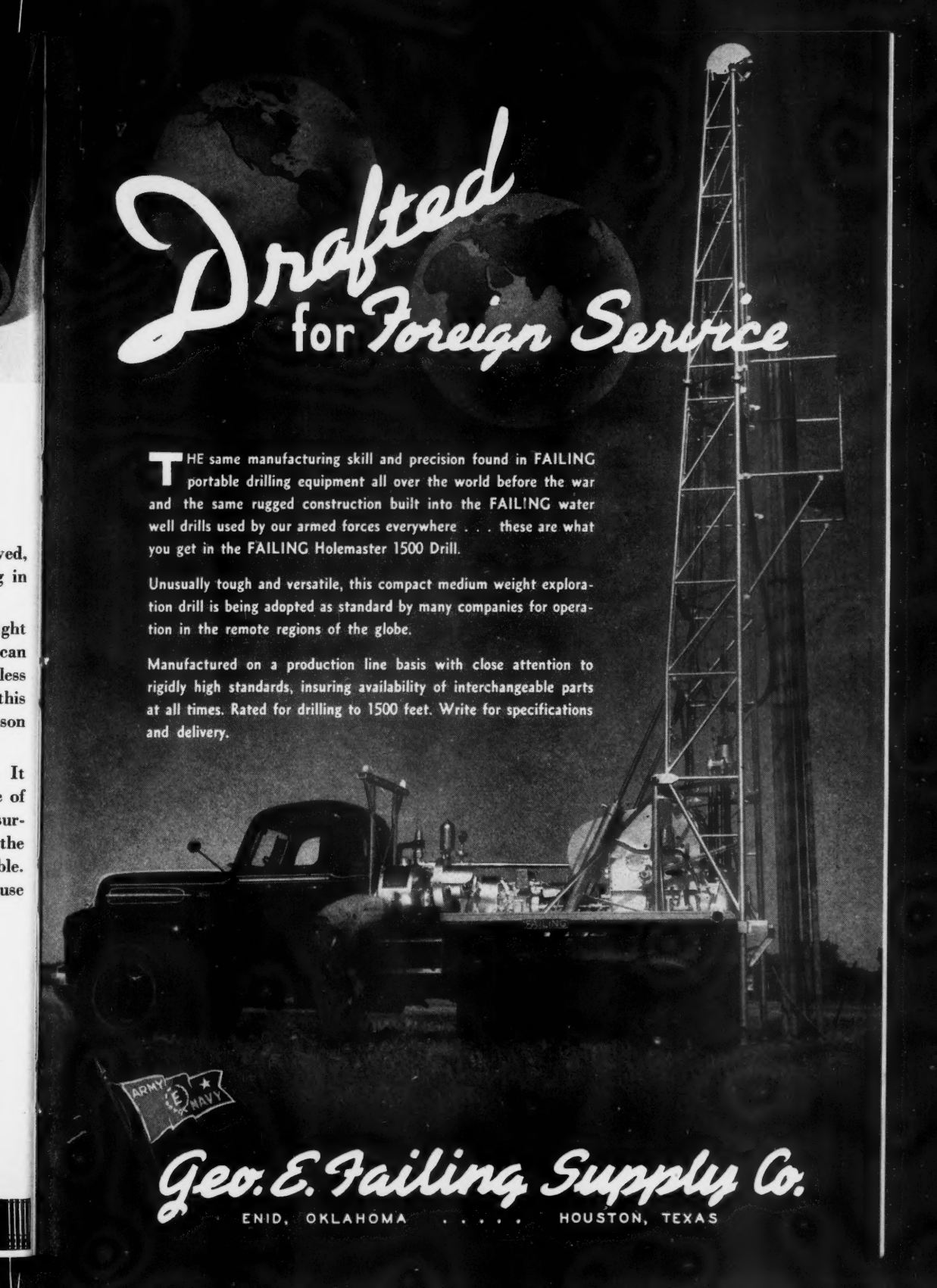
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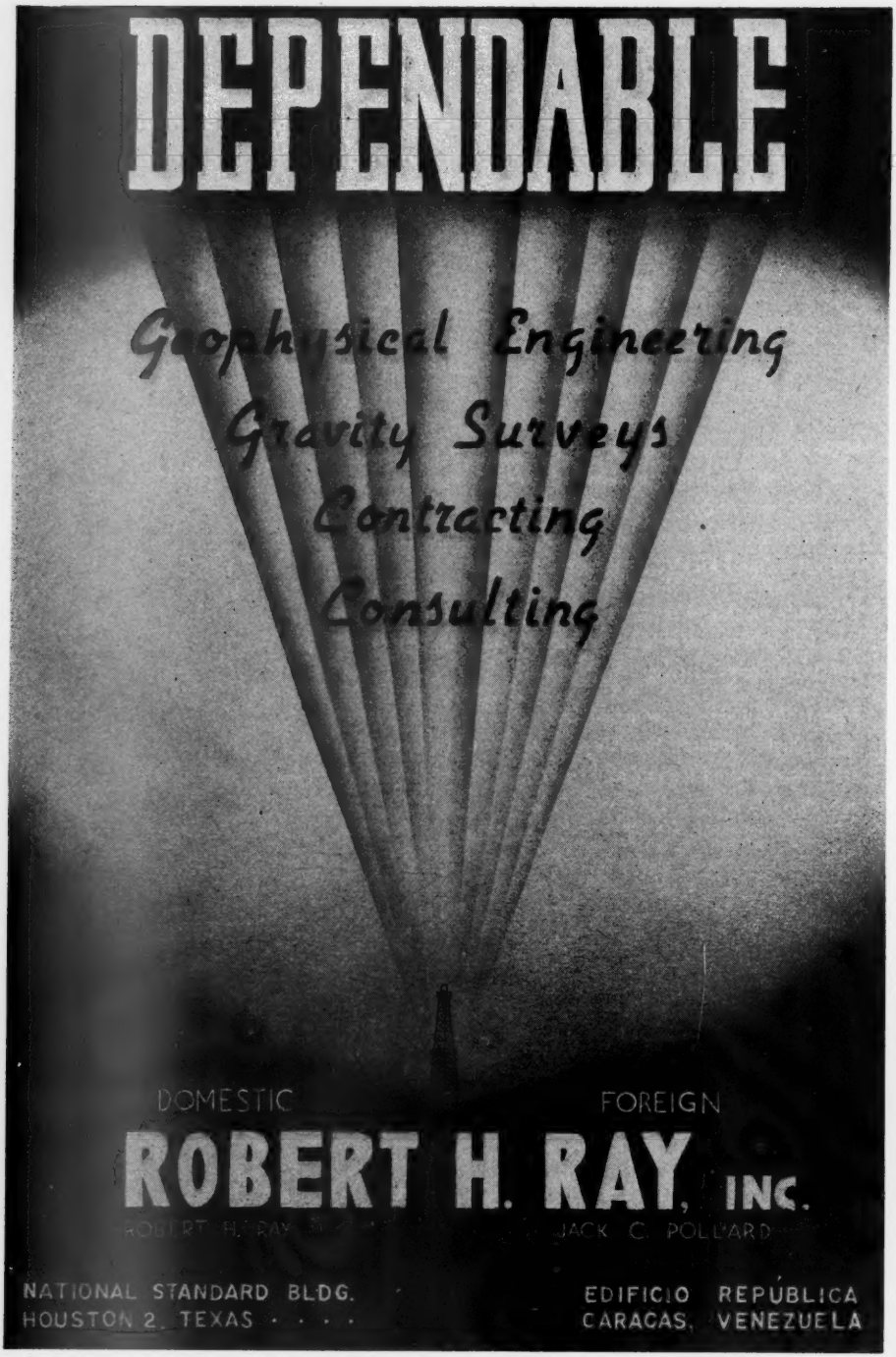
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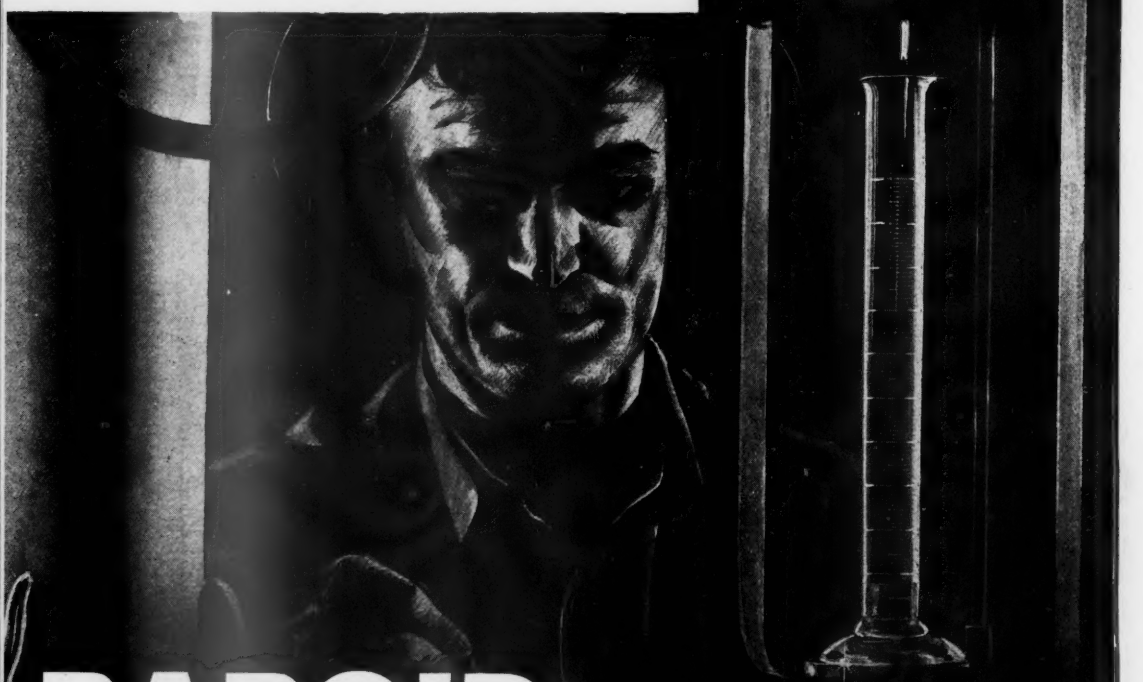

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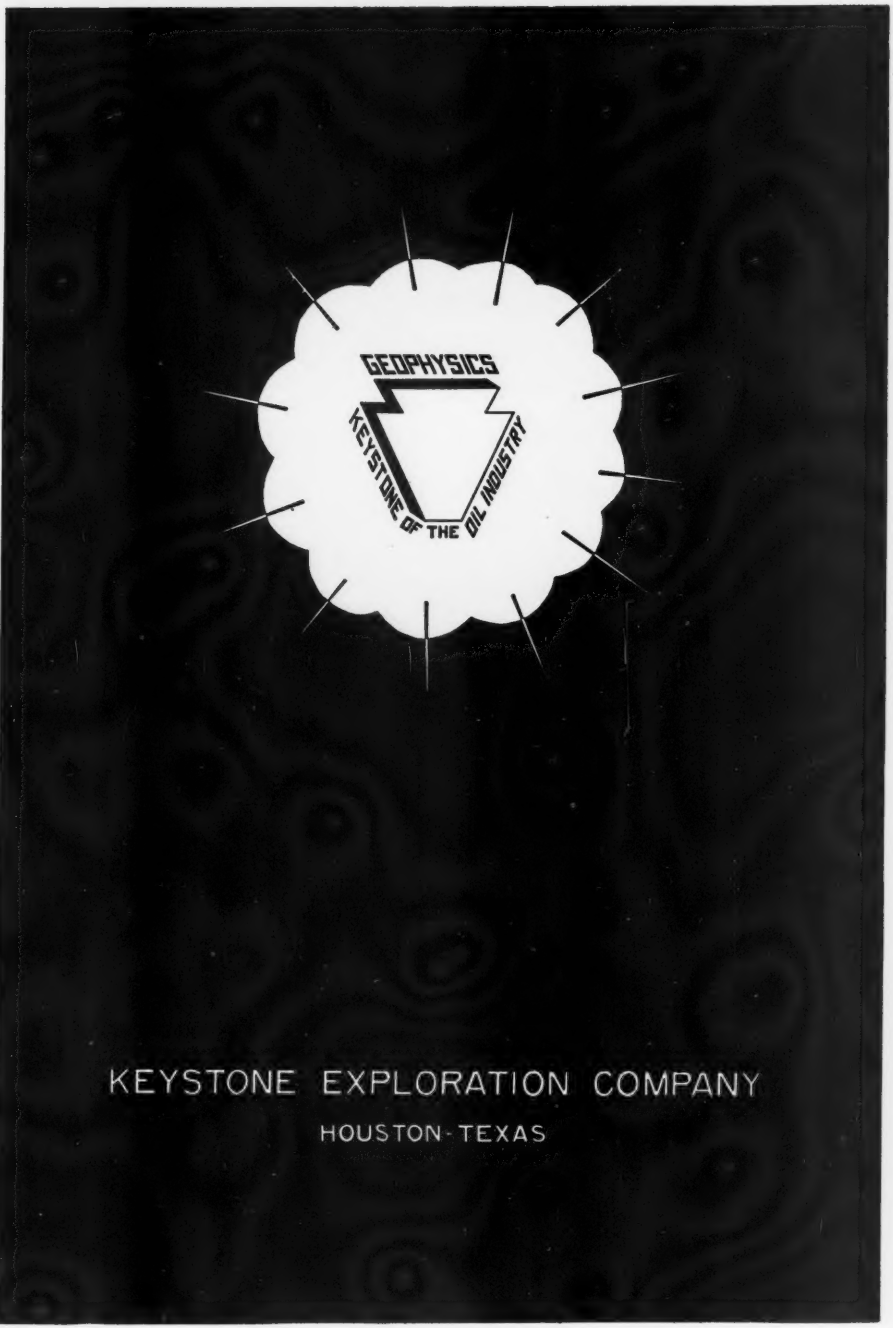
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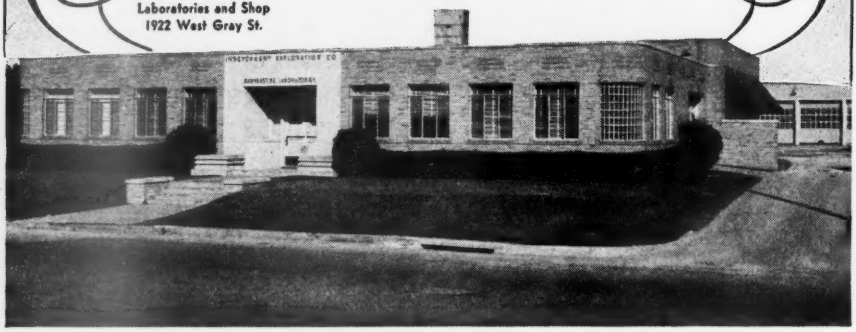

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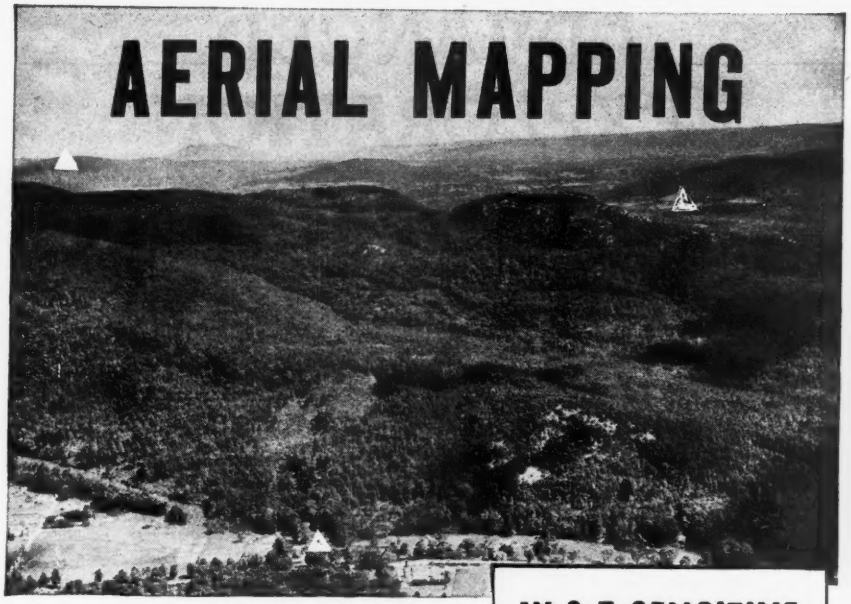

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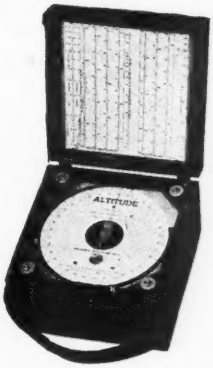

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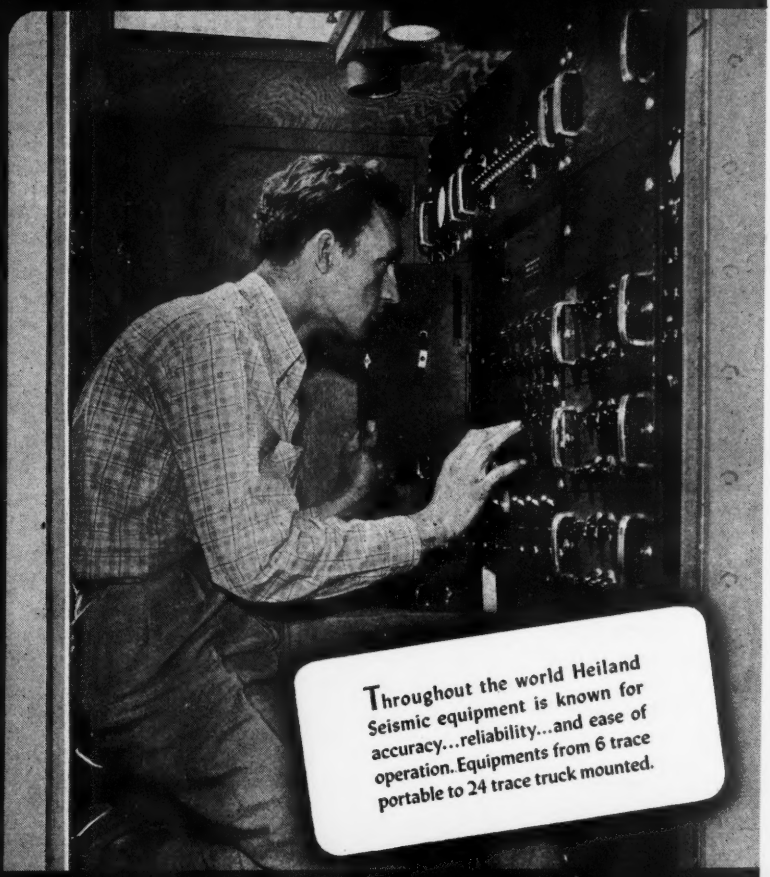

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